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energy-autonomous Portable Access points for INfrastructure-LESS networks

This project has received funding from the European Union's Horizon 2020 research and innovation programme 2014-2018 under the Marie Sklodowska-Curie grant agreement No. 812991

PAINLESS at a glance http://painless-itn.com/

PROJECT	H2020-MSCA-ITN-2018 – No: 812991
TITLE	**PAINLESS: energy-autonomous Portable Access points for INfrastructure-LESS networks**
FUNDER	European Commission
DATES	1st October 2018 – 30th September 2022

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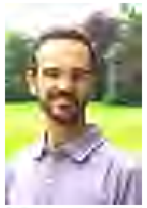

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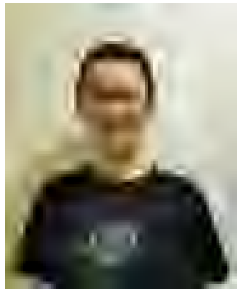

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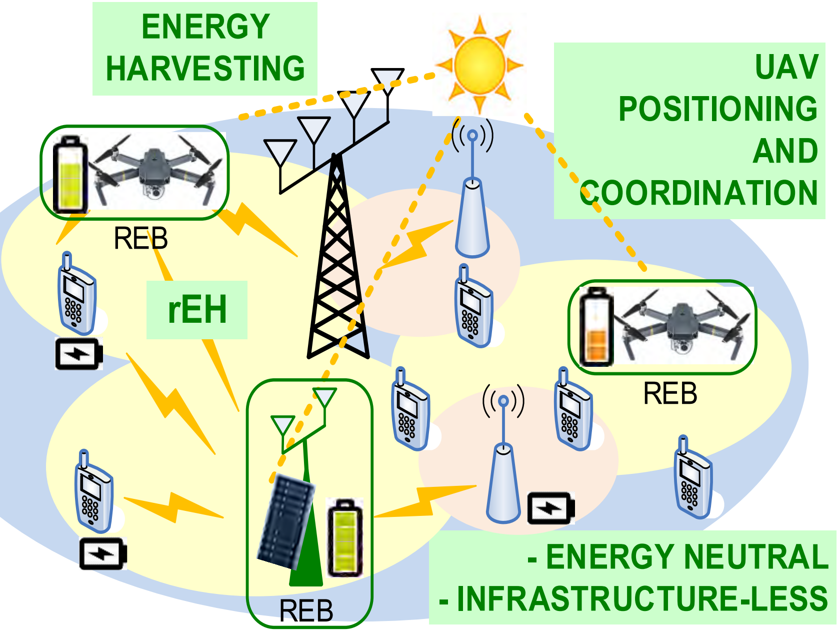
PAINLESS Approach

energy-autonomous Portable Access points for INfrastructure-LESS networks

Need for Network Coverage beyond the reach of the Power Grid → Paradigm Shift: Energy Efficient → **Energy Autonomous** → Integration of Comms Networks with Renewable Sources and Energy Storage



Objective 1. Establish a **training platform** for energy-autonomous BSs

Objective 2. Promote ***energy-autonomy*** in infrastructure-less networks

Objective 3. Joint management of **energy generation / harvesting, storage and consumption** for future networks

Objective 4. Enable **flexible, off-the-grid**, portable access points

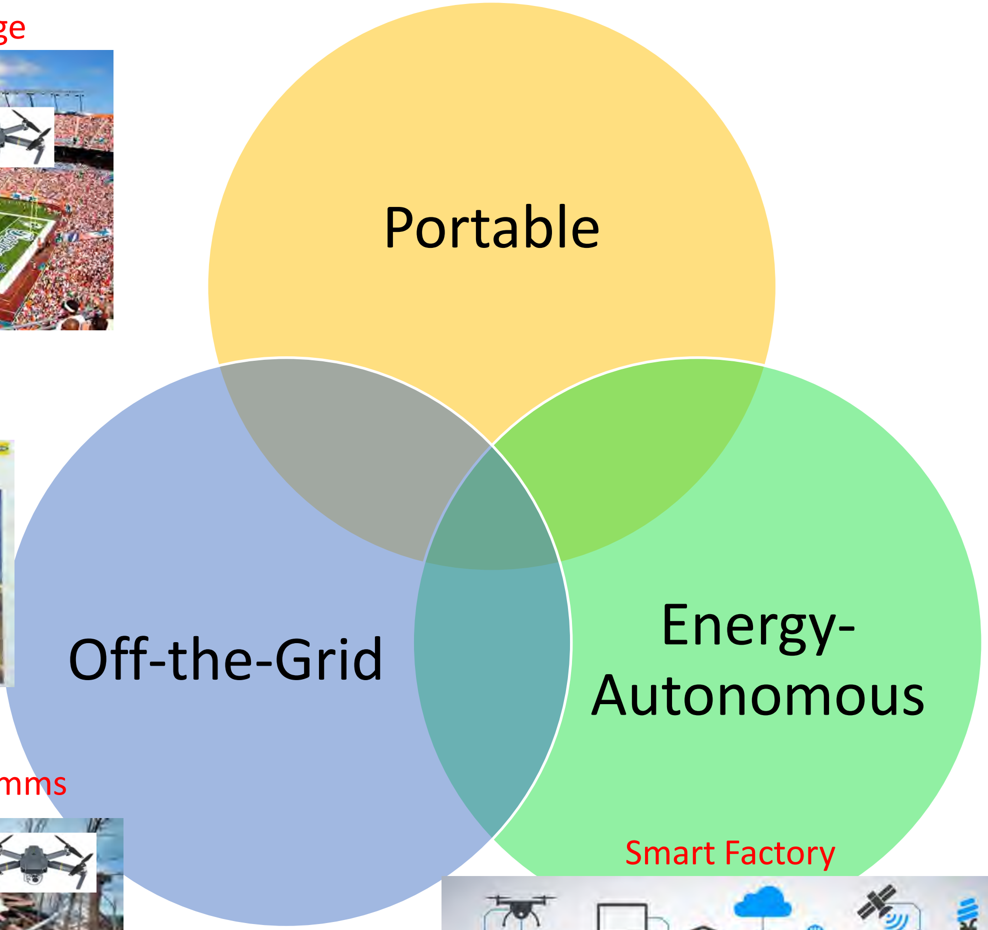
Objective 5. Define and **demonstrate** energy-autonomy

PAINLESS Scope

On-demand Coverage

Remote Coverage

Emergency / Disaster Comms



Smart Factory

WP3: Research Program (**ALBA**)

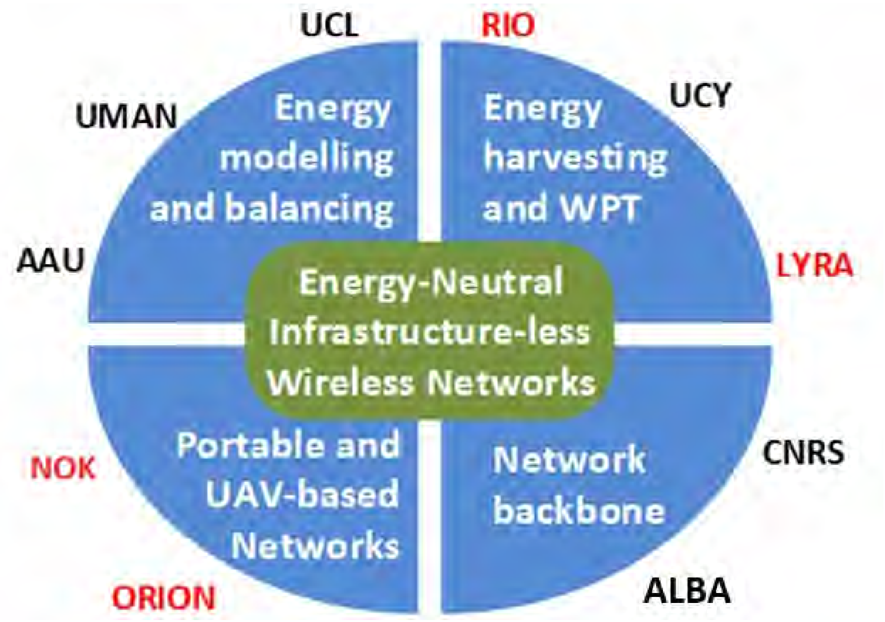
T3.1 Energy modelling, balancing and optimisation for portable access points (UCL)

T3.2 Enabling EN Techniques (UMAN)

T3.3 UAV cell planning, coordination, and control (CNRS)

T3.4 Radiated EH and Optimization (UCY)

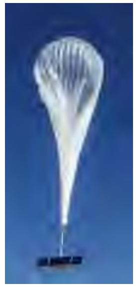
T3.5 Integration and Proof of Concept (AAU)

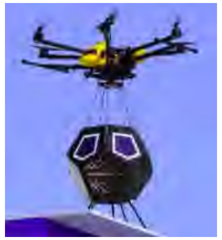


PAINLESS Scenarios (D2.2) [NOK]

- **Outdoor Broadband Access**
  - Capacity & range extension in urban / sub-urban nets
  - Rural / remote rural access
  - Special events (sports arenas, concerts, etc.)
  - Emergency events (traffic jams, train accidents, etc.)
  - Moving nets? (cars, ships, etc.)
- **Indoor Broadband Access**
  - Office / corporate / public indoor access
  - Large indoor (e.g. special events, etc)
  - Emergency (in subways, malls, etc.)
  - Other?
- **Outdoor Massive IoT**
  - Large-scale outdoor sensor networks
  - Other?
- **Indoor URLLC**
  - Factory floors (Industry 4.0)
  - Indoor logistics
  - Other?

Scenarios Impact:
- The comms channel
- The connectivity / network topology
- Energy sources
- Performance metrics
- UAV technology
- …

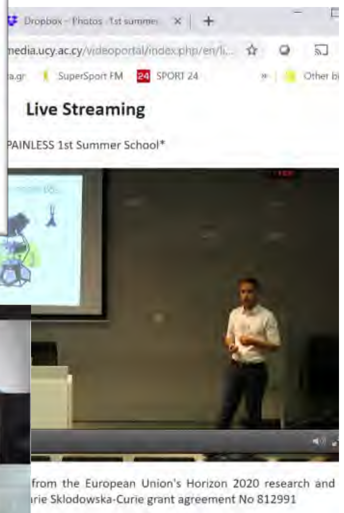


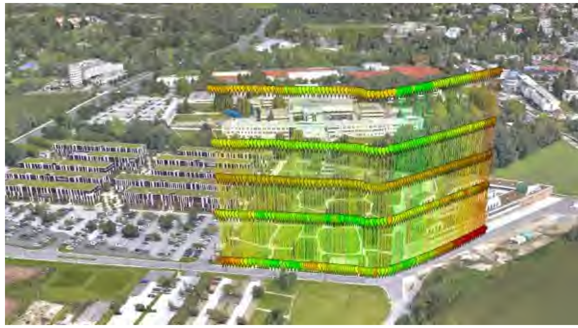


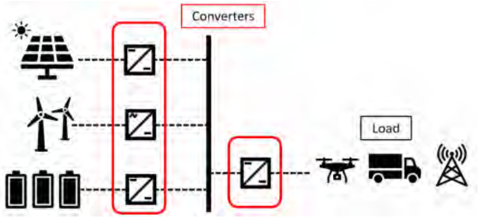
Activities, Outputs

http://painless-itn.com/dissemination/

- 5 Summer/Winter Schools
- 36 Publications – 1 Best Paper award
- 10 Conference Tutorials
- 6 Conference Workshops
- 1 Standards Contribution







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Wireless Powered Communications in the Era of 6G: A Bottom-up Multi-layer Approach

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May 9, 2022

IRIDA
Research Centre for Communication Technologies

Outline

1. Introduction & Basic Background
   - Wireless Power Transfer Technologies
   - Wireless Powered Communications
2. Research Studies
   - Mathematical modelling
   - Fundamental limits
   - Link-layer design
   - System-level design
   - Experimental studies
3. Conclusion

Outline

1 Introduction & Basic Background
- Wireless Power Transfer Technologies
- Wireless Powered Communications

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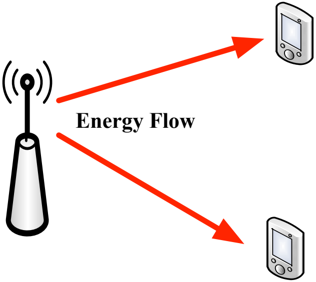
3 Conclusion

Wireless Power Transfer Technologies

Wireless Power Transfer (WPT) $\rightarrow$ deliver power wirelessly (without wires) through a generated/controlled electromagnetic field.

- Continuous, stable, and fully-controlled (vs. ambient energy harvesting).
- Applications with critical quality-of-service (QoS) constraints.



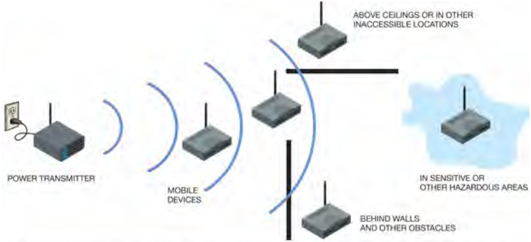
Three technologies available:

1. Inductive coupling.
2. Coupled magnetic resonance.
3. Electromagnetic (EM) radiation.

3. Electromagnetic Radiation

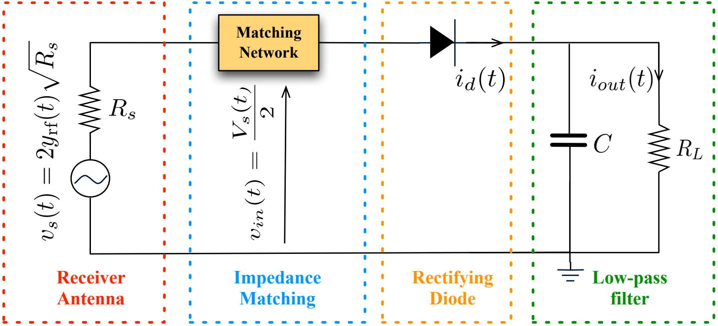
- Electromagnetic radiation uses propagation waves for WPT

  → antennas are used to transmit and receive energy signals **(far-field)**.



  - **Long range**, small TX/RX devices, flexibility, multicasting, mobility, LOS/NLOS environments, easy implementation in wireless communication systems.
  - Low efficiency, safety issues.
  - Industry: PowerCast, Ossia / Industrial standard: **3GPP Passive IoT**.
  - Applications: Wireless sensor networks, consumer electronics, IoT, RFID tags etc.

Rectenna Model



Physics-based diode model

Output DC current: Time average of the diode current $i_d(t)$

$$i_{out} = \mathbb{E}[i_d(t)] \approx \sum_{i \text{ even}}^{n_0} k_i \mathbb{E}[y_{rf}(t)^i]$$

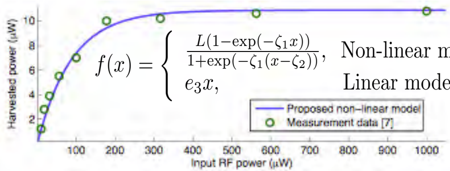
Linear model $(n_0 = 2) : i_{out} = k_2 P_{RF}^r$

Non-linear model $(n_0 = 4) : i_{out} = k_2 P_{RF}^r + k_4 (P_{RF}^r)^2$

Curve fitting diode model

Parametric non-linear function/curve fitting $P_{DC}^r = f(P_{RF}^r)$

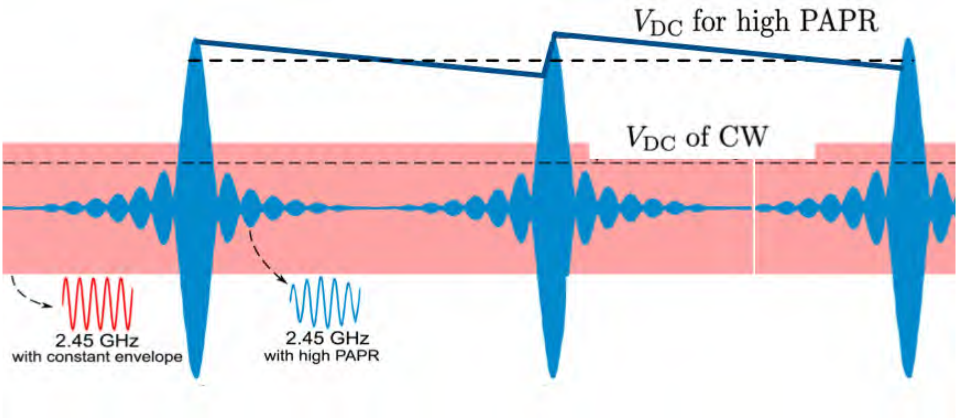
$$f(x) = \begin{cases} \frac{L(1-\exp(-\zeta_1 x))}{1+\exp(-\zeta_1(x-\zeta_2))}, & \text{Non-linear model} \\ e_3 x, & \text{Linear model} \end{cases}$$



Wireless Power Transfer: PAPR

Signals with high peak-to-average power ratio (PAPR) boost the wireless energy harvesting e.g., multisine signals, OFDM, chaotic signals etc.

- High-power amplifier (HPA) nonlinearities (?)
- PAPR enhances WPT but deteriorates information transfer.

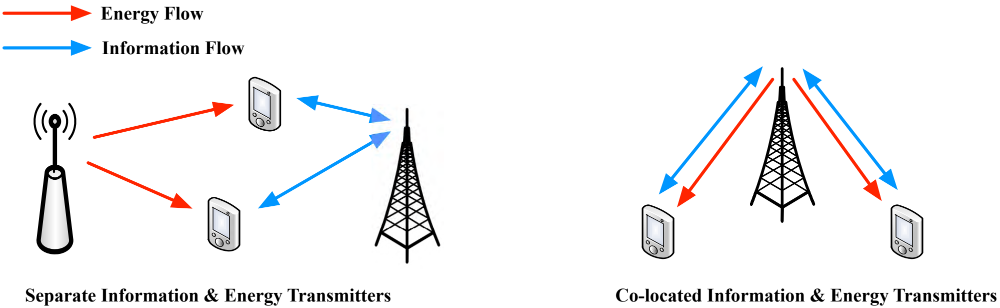


Outline

Wireless Powered Communications- Network architectures

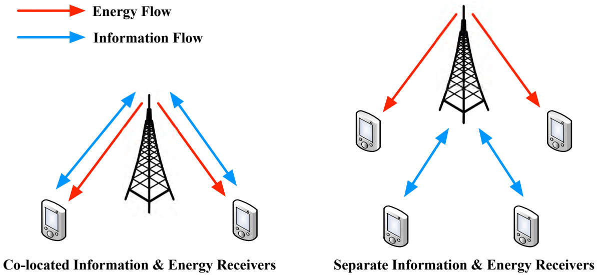
Wireless Powered Communications (WPC) - integration of the WPT process in wireless communication systems (**energy** and **information** flows co-exist).

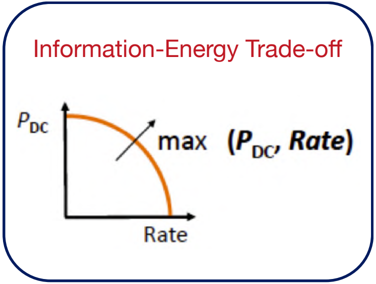
1. Wireless Powered Communications Networks (WPCN)
   - **Orthogonal (frequency/time)** information and power transfer.
   - Trade-off due to orthogonalization; design is optimized for each operation mode.



Wireless Powered Communications: Network Architectures (2)

2. Simultaneous Wireless Information and Power Transfer (SWIPT)
   - **Simultaneous (same waveform)** information and power transfer.

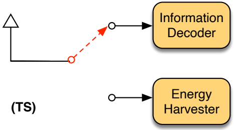


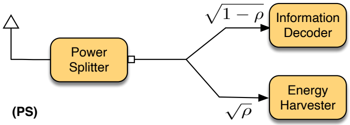


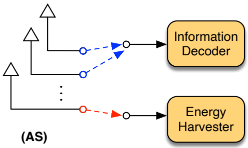
- Fundamental information-energy trade-off
  - TX signal design; input distribution, modulation, waveform, precoding etc.
  - Receiver structure/signal processing techniques (Wireless devices).

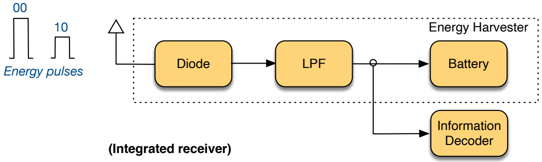
Practical Receiver Structures

- Information theoretic studies assume that a signal simultaneously can be used for decoding/harvesting (outer bound) [Varshney'08].
- Practical techniques: time switching (TS), power splitting (PS), antenna switching (AS); integrated receiver.







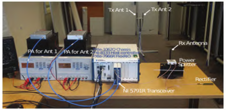


A Bottom-up Cross-Layer Research Approach

Advanced signal processing technologies for wireless powered communications (APOLLO)

European Research Council
Established by the European Commission

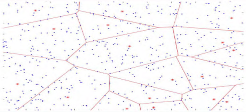
Experimental



- Software-defined Radio
- Fine-tune theoretical models

✓ **Microwaves/antenna**

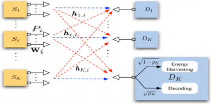
System-level



- Macroscopic modeling, analysis
- Cellular, ad-hoc architectures
- Multi-user interference, randomness

✓ **Stochastic Geometry, probability theory**

Link Design

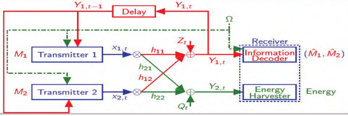


- Waveforms, modulation, precoding
- SWIPT architectures

✓ **Signal processing**

✓ **Optimization theory**

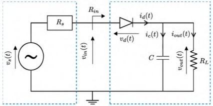
Fundamentals Limits



- Trade-off information-energy
- Input distribution

✓ **Information theory**

Modelling



- Accurate rectenna modeling
- Non-idealities (RC filter etc)

✓ **Circuit analysis**

Bottom-up design approach

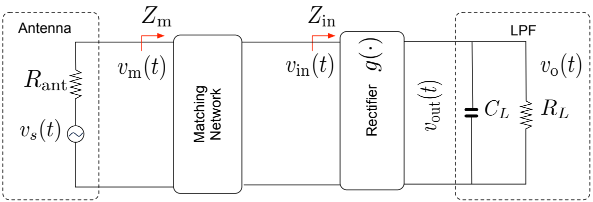
Outline

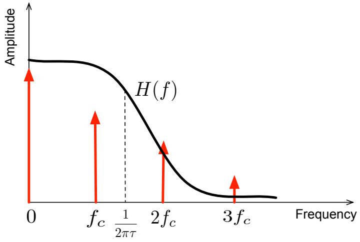
Outline

RC Filter Design for WPT- A Fourier Series Approach

Low-pass resistor-capacitor (RC) filter is an essential component of a rectenna circuit.

- RF bandwidth by removing the harmonics ($f_{\text{cut}} \uparrow \Rightarrow$ RF band $\uparrow \Rightarrow$ DC voltage $\uparrow$)
- DC ripple voltage at the output of the rectifier ($f_{\text{cut}} \uparrow \Rightarrow$ DC voltage ripple $\uparrow$).





A mathematical framework (Fourier series) to capture the **trade-off between DC voltage (harvesting) and DC ripple**.

RC Filter Design for WPT- Proof Sketch

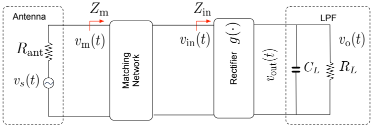
- Source's sinewave signal: $x(t) = A\cos(\omega_c t),\ 0 \leq t \leq T$.
- Full/half-wave rectifier i.e., $g(x) = |x|$ and $g(x) = \max(0, x)$.
- The input voltage at the rectifier: $v_{\text{in}}(t) = \delta A\cos(\omega_c t)$ with $\delta \triangleq \sqrt{\frac{R_L}{1+\omega_c^2\tau^2}}$.
- Rectifier's output (periodic/real): $v_{\text{out}}(t) = \delta A\left(\frac{a_0}{2} + \sum_{k=1}^{\infty} d_k \cos(\omega_c kt + \phi_k)\right)$, where a_k, b_k are the Fourier coefficients, $d_k = \sqrt{a_k^2 + b_k^2}$, and $\phi_k = \tan^{-1}(-b_k/a_k)$.
- RC filter (transfer function) i.e., $H(f) = \frac{R_L}{1+\jmath 2\pi f R_L C_L} = |H(f)|e^{j\angle H(f)}$.
- RC filter output: $v_{\text{o}}(t) = \delta A\left(\frac{a_0 R_L}{2} + \sum_{k=1}^{\infty} |H(kf_c)| d_k \cos(\omega_c kt + \phi_k + \angle H(kf_c))\right)$

Ripple peak: $\rho = \delta A R_L\left(\frac{a_0}{2} + \sum_{k=1}^{\infty} \frac{d_k \cos(\phi_k)}{\sqrt{1+(2\pi k f_c \tau)^2}}\right)$.

- $f_{\text{cut}} \to \infty \Rightarrow \rho(\max)$.

DC voltage: $V_{\text{DC}} = \mathbb{E}_t\{v_o(t)\} = \delta A R_L \frac{a_0}{2}$,

- $f_{\text{cut}} \to \infty \Rightarrow V_{\text{DC}}(\max)$, $f_{\text{cut}} \to 0 \Rightarrow V_{\text{DC}} = 0$.



RC Filter Design for WPT- Results

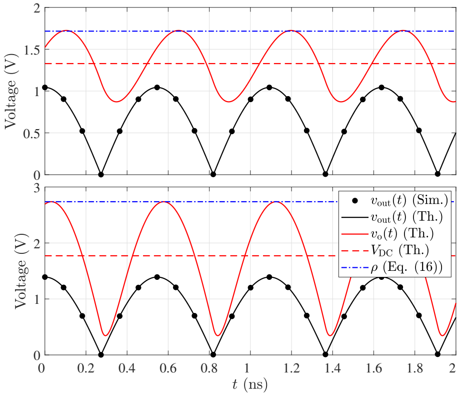


Figure: Output voltage versus t; top: $f_{\mathrm{cut}} = 1$ GHz, bottom: $f_{\mathrm{cut}} = 5$ GHz.

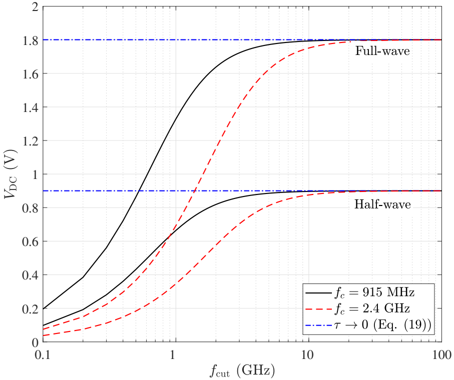
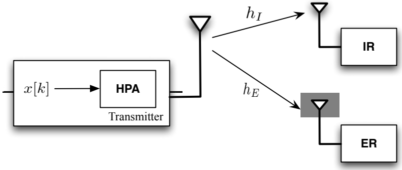


Figure: V_{DC} in terms of the cut-off frequency f_{cut}.

- A higher f_{cut} (i.e., a lower $R_L C_L$), the system achieves a higher DC voltage but there is also a larger ripple.
- V_{DC} converges to its maximum value as f_{cut} increases.

Outline

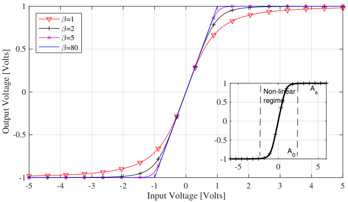
SWIPT with Power Amplifier Nonlinearity



- Information-Energy capacity region (?)
- Input distribution (?)

- PAM signal $x(t) = \sum_{k=-\infty}^{\infty} x[k]p(t - kT)$, with rectangular $p(t)$.
- $x[k]$ i.i.d real random variable X with CDF $F_X(x)$.
- AP: $\mathbb{E}[X^2] \leq \sigma_x^2$, PP: $|X| \leq A$, where A is the peak amplitude.
- Energy harvesting $\propto \mathbb{E}\left[I_0(Bh_E|\hat{X}|)\right]$ (power channel).
- Solid state power amplifier (SSPA) model i.e., $\hat{X} = d(X)$.

$$d(r) = \frac{r}{\left[1 + \left(\frac{r}{A_s}\right)^{2\beta}\right]^{\frac{1}{2\beta}}},$$



Power Ampl. Nonlinearity: Information-Energy Capacity Region

- We consider firstly the case where the IR is not present/active.

$$(P1) \quad \max_{F_X} \quad \mathbb{E}\left[I_0(Bh_E|\hat{X}|)\right]$$
$$\text{s.t.} \quad \mathbb{E}[X^2] \leq \sigma_x^2, |X| \leq A.$$

- The optimal input probability function F_X is binary or ternary.

- We consider the case where the target of the system is to maximize the Shannon information capacity under both AP and PP constraints.

$$(P2) \quad \max_{F_X} \quad I(X;Y)$$
$$\text{s.t.} \quad \mathbb{E}[X^2] \leq \sigma_x^2, |X| \leq A,$$

- F_X is unique, finite and discrete [Smith, 1971].
- For small A, there is no trade-off between information/energy (binary input distribution)

- The other points of the boundary $I_{\min} \leq I \leq I_{\max}$ and $\mathcal{E}_{\min} \leq \mathcal{E} \leq \mathcal{E}_{\max}$; see (P2) with the extra constraint $\mathcal{E}_{\min} \leq \mathbb{E}[I_0(Bh_E|\hat{X}|)] \leq \mathcal{E}_{\max}$.

Power Ampl. Nonlinearity: Numerical Results

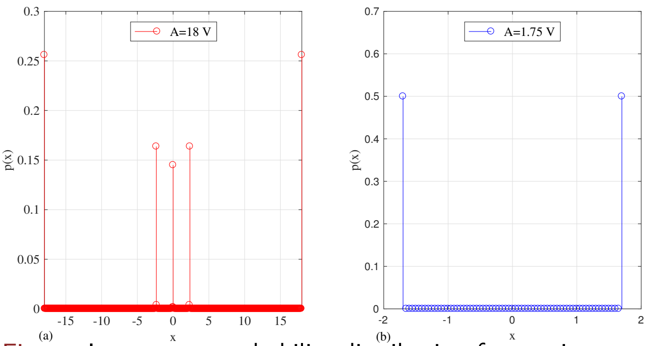


Figure: Input mass probability distribution for maximum information transfer; $\beta = 1$, $B = 0.5$, $\sigma_x^2 = 30$ dB, and (a) $A = 18$, and (b) $A = 1.75$.

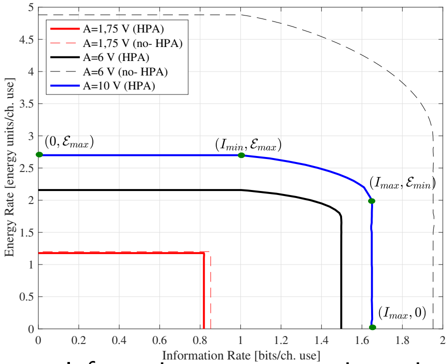


Figure: Information-energy capacity region; $A_s = 5$, $\beta = 1$, $B = 0.5$, $\sigma_x^2 = 30$ dB.

Outline

Tone-index Multisine (TIM) Modulation

- Signals with high PAPR boost wireless energy harvesting e.g., multisine signals.
- Conventional SWIPT architectures have high complexity (e.g., RF chain, channel estimation etc) $\rightarrow$ Avoid active elements and expensive signal processing.

TIM modulation: Continuous transmission of multisine waveforms from a predefined set, information is embedded in the number of the the tones.

- Integrated receiver, non-coherent maximum-likelihood (ML) detection.

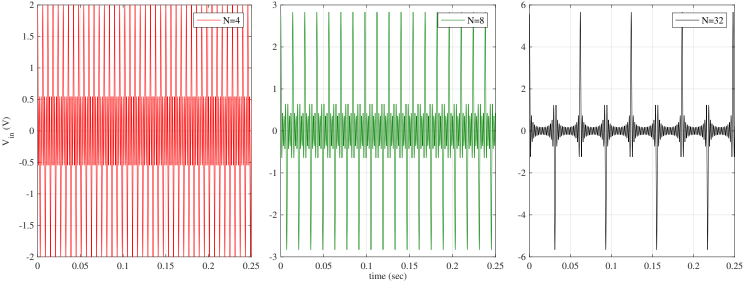
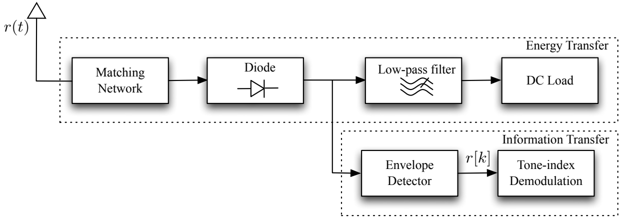


Figure: Time-domain waveform of a N-tone signal with $N \in \{4, 8, 32\}$; the transmitter conveys $\log_2(3) \approx 1.58$ bits of information.

TIM: Receiver Architecture and Analysis (1)



Unmodulated N-tone multisine signal of bandwidth W with zero phase arrangement and intercarrier frequency spacing $\Delta f^{(N)}$.

- **Received signal:** $r(t) = \sqrt{\frac{2P}{N}} \Re \left\{ \frac{\sin(\pi N \Delta f^{(N)} t)}{\sin(\pi \Delta f^{(N)} t)} h(t) e^{j2\pi f_c t} \right\} + n(t)$.
- **Linear envelope detection:** $r[k] = hx^{(N)}[k] + n[k]$, with $1 \leq k \leq K$, where $x^{(N)}[k]$ denotes the k-th sample of the transmitted waveform.

RF energy harvesting: The average DC harvested energy (physics-based diode model) is equal to $Q = \frac{1}{|\mathcal{S}|} \sum_{N \in \mathcal{S}} Q_N \approx k_2 \sigma_h^2 P + \frac{3k_4 \sigma_h^4 P^2}{|\mathcal{S}|} \sum_{N \in \mathcal{S}} N$, where k_2 and k_4 depend on the characteristics of the rectification circuit.

TIM: Receiver Architecture and Analysis (2)

ML detection and average error probability

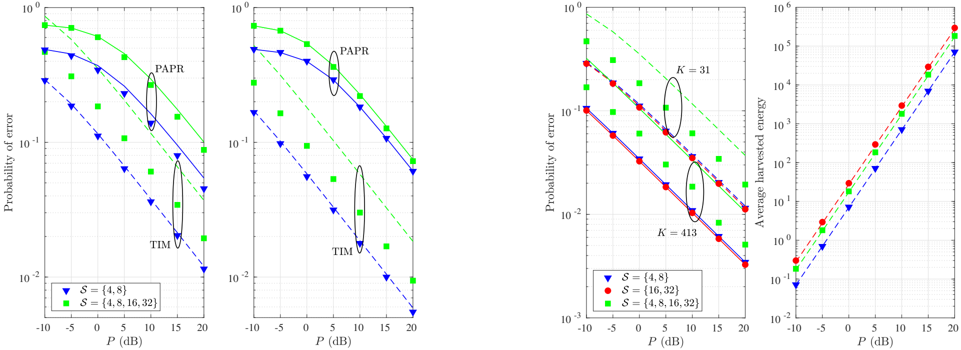
- Conditioned on the transmitted signal $\mathrm{x}^{(i)} = [x^{(i)}[1], x^{(i)}[2], \cdots, x^{(i)}[K]]^T$, the received vector r is Gaussian with PDF $p(\mathrm{r}|\mathrm{x}^{(i)}) = \frac{1}{\sqrt{|2\pi \mathrm{R}_i|}} e^{-\frac{1}{2}\mathrm{r}^T \mathrm{R}_i^{-1} \mathrm{r}}$, where $\mathrm{R}_i = \sigma_n^2 \mathrm{I} + \sigma_h^2 \mathrm{x}^{(i)} (\mathrm{x}^{(i)})^T$ denotes the covariance matrix.
- The ML detector (log-likelihood): $\hat{N} = \arg\max_{i \in \mathcal{S}} p(\mathrm{r}|\mathrm{x}^{(i)}) = \arg\max_{i \in \mathcal{S}} \log p(\mathrm{r}|\mathrm{x}^{(i)})$.
- The pairwise error probability is equal to $\mathbb{P}\{\mathrm{x}^{(i)} \rightarrow \mathrm{x}^{(j)}\} = \mathbb{P}\left\{\zeta^T \mathrm{R}_i^{\frac{T}{2}} \left(\mathrm{R}_i^{-1} - \mathrm{R}_j^{-1}\right) \mathrm{R}_i^{\frac{1}{2}} \zeta > \phi_{ij}\right\}$, where $\phi_{ij} = \log(|\mathrm{R}_j|/|\mathrm{R}_i|)$ and the vector $\zeta = \mathrm{R}_i^{-\frac{1}{2}} \mathrm{r}$ (i.i.d. zero-mean, unit-variance real Gaussian).

ML pairwise error probability

$\mathbb{P}\{\mathrm{x}^{(i)} \rightarrow \mathrm{x}^{(j)}\} = \frac{1}{\pi} \sum_{j=0}^{\infty} \frac{-2\sqrt{-1}}{j!(2j+1)} \left(\frac{\mu_2}{\mu_1}\right)^{j+\frac{1}{2}} \Gamma\left(j + \frac{3}{2}\right) e^{-\frac{z_0}{2}} U\left(\frac{1}{2}, -j, \frac{z_0}{2}\right)$, where $z_0 = \max(0, \phi_{ij}/\mu_2)$ and $U(\cdot,\cdot,\cdot)$ is the confluent hypergeometric function of the first kind. The union bound can be written as $P_e^{\mathrm{TIM}} \leq \frac{1}{|\mathcal{S}|} \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{S}, j \neq i} \mathbb{P}\{\mathrm{x}^{(i)} \rightarrow \mathrm{x}^{(j)}\}$, where $|\mathcal{S}|$ is the cardinality of $\mathcal{S}$.

TIM: Numerical Results

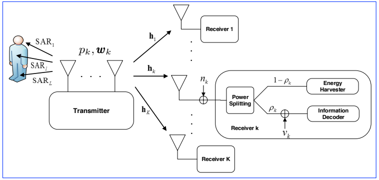
- $\sigma_h^2 = 1$, $\sigma_n^2 = 1$, $W = 1$ kHz, $k_2 = 0.0034$ and $k_4 = 0.3829$, $K = 31$ samples/symbol.



- TIM modulation outperforms the PAPR approach; higher gains for a larger symbol time.
- $\{16, 32\}$ achieves the best performance with respect to both the error probability and the average harvested energy.
- A larger K provides a lower probability of error; no effect on EH.

SWIPT MISO Downlink with SAR

Specific absorption rate (SAR) i.e., rate of energy absorption per unit mass at a specific location in the tissue [W/Kg]; **quadratic form constraint** (phase difference).



$$y_k = \underbrace{\mathbf{h}_k^\dagger \mathbf{w}_k s_k}_{\text{Information signal}} + \underbrace{\sum_{j\neq k} \mathbf{h}_k^\dagger \mathbf{w}_j s_j}_{\text{Interference}} + n_k,$$

$$P_k^r = \sum_{j=1}^{K} |\mathbf{h}_k^\dagger \mathbf{w}_j|^2 + N_0.$$

$$\Gamma_k = \frac{\rho_k |\mathbf{h}_k^\dagger \mathbf{w}_k|^2}{\rho_k \left(N_0 + \sum_{j\neq k} |\mathbf{h}_k^\dagger \mathbf{w}_j|^2\right) + N_C}, \quad P_k^S = F((1-\rho_k)P_k^r).$$

- **Optimization problem**: Maximize the ratios of the received SINR and EH over the target requirements subject to the SAR and total power constraints

P1:
$$\begin{aligned}
\max_{\{\mathbf{w}_k,\rho_k,t\}} \quad & t \\
\text{s.t.} \quad & \frac{|\mathbf{h}_k^\dagger \mathbf{w}_k|^2}{\sum_{j=1,j\neq k}^{K} |\mathbf{h}_k^\dagger \mathbf{w}_j|^2 + N_0 + \frac{N_C}{\rho_k}} \geq t\bar{\gamma}_k \triangleq \gamma_k, \\
& F\left((1-\rho_k)\left(\sum_{j=1}^{K} |\mathbf{h}_k^\dagger \mathbf{w}_j|^2 + N_0\right)\right) \geq t\bar{\lambda}_k \triangleq \tilde{\lambda}_k, \\
& 0 \leq \rho_k \leq 1, \forall k, \\
& \sum_{k=1}^{K} \mathbf{w}_k^\dagger \mathbf{A}_l \mathbf{w}_k \leq P_l, \forall l, \\
& \sum_{k=1}^{K} \|\mathbf{w}_k\|^2 \leq P_T,
\end{aligned}$$

P2:
$$\begin{aligned}
\min_{\{\mathbf{w}_k,\rho_k\}} \quad & \sum_{k=1}^{K} \|\mathbf{w}_k\|^2 \\
\text{s.t.} \quad & \frac{|\mathbf{h}_k^\dagger \mathbf{w}_k|^2}{\sum_{j=1,j\neq k}^{K} |\mathbf{h}_k^\dagger \mathbf{w}_j|^2 + N_0 + \frac{N_C}{\rho_k}} \geq \gamma_k, \\
& (1-\rho_k)\eta_k \left(\sum_{j=1}^{K} |\mathbf{h}_j^\dagger \mathbf{w}_k|^2 + N_0\right) \geq F^{-1}(\tilde{\lambda}_k) \triangleq \lambda_k, \\
& 0 \leq \rho_k \leq 1, \forall k, \\
& \sum_{k=1}^{K} \mathbf{w}_k^\dagger \mathbf{A}_l \mathbf{w}_k \leq P_l, \forall l.
\end{aligned}$$

SWIPT MISO Beamforming with SAR

1. Fixed Beamforming
   - Fixed beamforming vector $\mathbf{w}_k = \sqrt{p_k}\mathbf{w}_k^f$, $\|\mathbf{w}_k^f\| = 1$, $G_{k,j} \triangleq |\mathbf{h}_k^\dagger \mathbf{w}_j^f|^2$ and $F_{k,l} = \mathbf{w}_k^{f\dagger}\mathbf{A}_l\mathbf{w}_k^f$.

$$
\begin{aligned}
\mathbf{P6}: \quad & \min_{\{p_k,\rho_k\}} && \sum_{k=1}^{K} p_k \\
\text{s.t.}(\frac{1}{\gamma_k}+1)G_{k,k}p_k &\geq && \frac{1}{\rho_k}N_C + \sum_{j=1}^{K} G_{k,j}p_j + N_0, \forall k, \\
\sum_{j=1}^{K} G_{k,j}p_j + N_0 &\geq && \frac{\lambda_k}{1-\rho_k}, \forall k, \\
p_k \geq 0, & && 0 \leq \rho_k \leq 1, \forall k, \\
\sum_{k=1}^{K} p_k F_{k,l} &\leq && P_l, \forall l.
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{w}_k^{MRT} &= \frac{\mathbf{h}_k}{\|\mathbf{h}_k\|}, \\
\mathbf{w}_k^{ZF} &= \frac{\left(\mathbf{I}_{N_t} - \mathbf{H}_k^{\ddagger}\mathbf{H}_k\right)\mathbf{h}_k}{\left\|\left(\mathbf{I}_{N_t} - \mathbf{H}_k^{\ddagger}\mathbf{H}_k\right)\mathbf{h}_k\right\|}, \\
\mathbf{w}_k^{RZF} &= (K\mathbf{I} + \mathbf{H}\mathbf{H}^\dagger + \sum_{l=1}^{L}\mathbf{A}_l)^{-1}\mathbf{h}_k,
\end{aligned}
$$

with $\mathbf{H} = [\mathbf{h}_1, \ldots, \mathbf{h}_K]$, and $\mathbf{H}_k = [\mathbf{h}_1, \ldots, \mathbf{h}_{k-1}, \mathbf{h}_{k+1}, \ldots, \mathbf{h}_K]$.

2. Hybrid MRT-ZF Beamforming
   - Beamforming vector $\mathbf{w}_k^{\text{hyb}} = \sqrt{x_k}\mathbf{w}_k^{ZF} + \sqrt{y_k}\mathbf{w}_k^{MRT}$, where x_k and y_k are combining coefficients.
   - The problem can be cast into a SOCP formulation; Gurobi solver.

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$$\begin{aligned}
\mathbf{P6}: \quad & \min_{\{p_k,\rho_k\}} \quad \sum_{k=1}^{K} p_k \\
\text{s.t.} & \left(\frac{1}{\gamma_k}+1\right)G_{k,k}p_k \geq \frac{1}{\rho_k}N_C + \sum_{j=1}^{K} G_{k,j}p_j + N_0, \forall k, \\
& \sum_{j=1}^{K} G_{k,j}p_j + N_0 \geq \frac{\lambda_k}{1-\rho_k}, \forall k, \\
& p_k \geq 0, \quad 0 \leq \rho_k \leq 1, \forall k, \\
& \sum_{k=1}^{K} p_k F_{k,l} \leq P_l, \forall l.
\end{aligned}$$

$$\begin{aligned}
\mathbf{w}_k^{MRT} &= \frac{\mathbf{h}_k}{\|\mathbf{h}_k\|}, \\
\mathbf{w}_k^{ZF} &= \frac{\left(\mathbf{I}_{N_t} - \mathbf{H}_k^{\ddagger}\mathbf{H}_k\right)\mathbf{h}_k}{\left\|\left(\mathbf{I}_{N_t} - \mathbf{H}_k^{\ddagger}\mathbf{H}_k\right)\mathbf{h}_k\right\|}, \\
\mathbf{w}_k^{RZF} &= (K\mathbf{I} + \mathbf{H}\mathbf{H}^\dagger + \sum_{l=1}^{L}\mathbf{A}_l)^{-1}\mathbf{h}_k,
\end{aligned}$$

with $\mathbf{H} = [\mathbf{h}_1, \ldots, \mathbf{h}_K]$, and $\mathbf{H}_k = [\mathbf{h}_1, \ldots, \mathbf{h}_{k-1}, \mathbf{h}_{k+1}, \ldots, \mathbf{h}_K]$.

2. Hybrid MRT-ZF Beamforming
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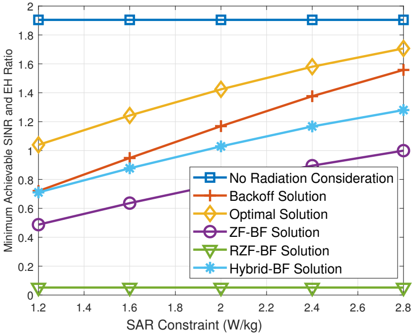
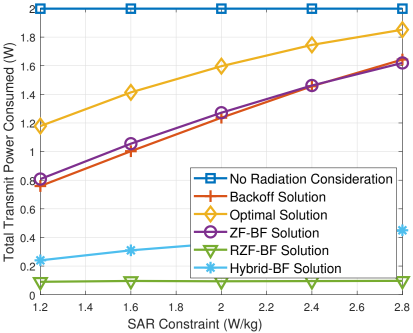
   - The problem can be cast into a SOCP formulation; Gurobi solver.

3. Optimal Beamforming scheme
   - Semidefinite programming (SDR) with rank-1 relaxation.

SWIPT MISO Downlink with SAR: Numerical Results

- $K = N_t = 4$, $N_0 = -70$ dBm and $N_C = -50$ dBm, $\bar{\Gamma}_k = \bar{\Gamma} = 10$ dB, $\bar{\lambda}_k = \bar{\lambda} = -15$ dBm, $P_T = 2$ W, $P_l = P = 1.6$ W/kg, Rice fading.
- $F_k(x) = \frac{\bar{a}x + \bar{b}}{x + c} - \frac{\bar{b}}{c}$ with $\bar{a} = 2.463$, $\bar{b} = 1.635$, $c = 0.826$.





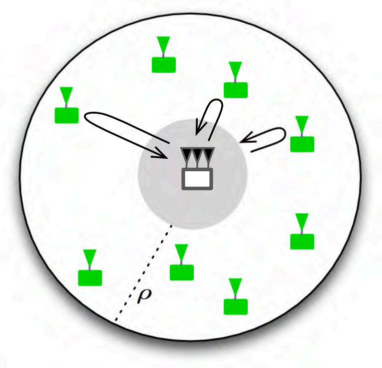
- The optimal solution can achieve substantial gain over the traditional backoff solution, especially when the SAR power constraint is low.
- The hybrid scheme is superior to the two fixed beamforming solutions.
- The hybrid scheme uses less power, thus higher power efficiency.

Outline

Retrodirective Energy Beamforming in Backscatter Multi-User Networks

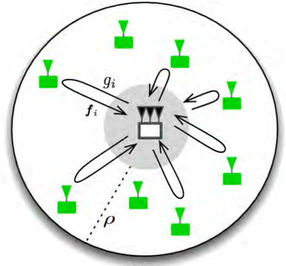
- Energy beamforming (EB) i.e., focusing the transmitted energy to the receivers' direction.
- Channel state information (CSI) at the transmitter e.g., feedback channel.

Retrodirective EB with backscattering: (a) Retrodirectivity i.e., retransmitting to the direction of arrival without processing, (b) Backscattering.

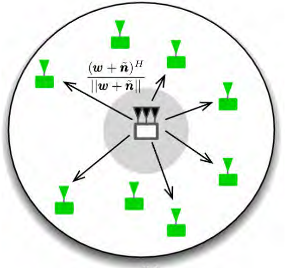


- Disc of radius ρ; exclusive zone of radius ξ.
- Energy transmitter (ET) has a large number of antennas M.
- Energy receivers (ERs) form an HPPP $\Phi = \{x_i\}$ with density λ.
- Transmission power P_T and $M \gg K$ (massive MIMO); channel reciprocity.
- β_i reflection coefficient for the i-th ER.
- Path-loss $d^{-\alpha}$ with $\alpha > 2$, Rayleigh fading.

Retrodirective Energy Beamforming: Two Phases



(a)



(b)

(a) Backscattering Phase

- ET broadcasts an unmodulated single-tone
$$x(t) = \sqrt{2P_t}\cos(2\pi f_c t),\ t \in [0, \tau]$$
- The received signal (complex equivalent) at the ET is given by $\boldsymbol{y}(t) = \sum_{x_k \in \Phi} \sqrt{\frac{\beta_k P_t}{M d_k^{2\alpha}}} g_k \boldsymbol{f}_k + \boldsymbol{n}(t)$, where $g_k = \sum_{m=1}^{M} f_{k,m}$.

(b) Energy Beamforming Phase

- Energy signal $\boldsymbol{x}_e = (\boldsymbol{w} + \tilde{\boldsymbol{n}})^H / ||\boldsymbol{w} + \tilde{\boldsymbol{n}}||$, where $\boldsymbol{w} = \sum_{x_k \in \Phi} \sqrt{\frac{\beta_k P_t}{M d_k^{2\alpha}}} g_k^* \boldsymbol{f}_k^H$; received signal $y_i = \sqrt{P_t d_i^{-\alpha}} \boldsymbol{x}_e \boldsymbol{f}_i + z$.
- Harvested energy at the i-th ER i.e.,
$$Q(\beta, d_i) = \zeta |y_i|^2 = \underbrace{\zeta P_t d_i^{-\alpha}}_{Q_{\mathrm{OM}}(d_i)} + \underbrace{\frac{\zeta P_t M d_i^{-3\alpha} \beta_i |g_i|^2}{\sum_{x_k \in \Phi} d_k^{-2\alpha} \beta_k |g_k|^2 + \frac{M\sigma^2}{P_t \tau}}}_{Q_{\mathrm{RE}}^{\Phi}(\beta, d_i)}.$$

Backscattering Policies / Average Harvested Energy

1. **Distance-Inversion Backscattering (DIB)** i.e., the reflection coefficient is a function of the location i.e., $\beta_i = (d_i/\rho)^{2\alpha}$; user fairness.

2. **Full Backscattering (FB)** i.e., $\beta_i = 1$ ($\forall\, x_i \in \Phi$).

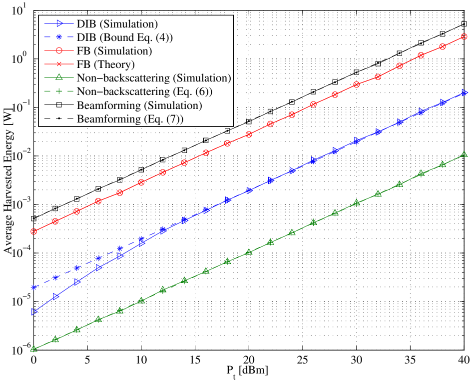
$$\mathcal{Q}_{\text{FB}} \rightarrow \Lambda(\xi, \rho) \quad \text{for} \;\; \lambda \rightarrow \infty, \;\; \text{[Non-backscattering]},$$
$$\mathcal{Q}_{\text{FB}} \rightarrow M\Lambda(\xi, \rho) \;\; \text{for} \;\; \lambda \rightarrow 0, \;\; \text{[CSI/Beamforming]}.$$

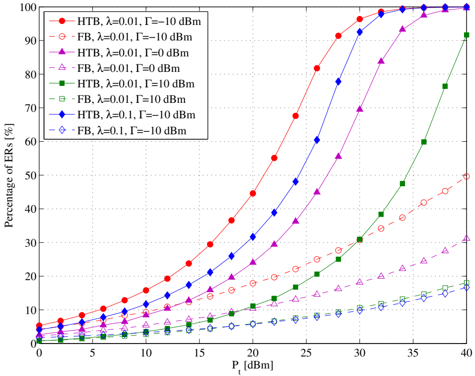
3. **Binary Backscattering schemes** i.e., $\beta_i \in \{0, 1\}$; control the retrodirective component and provide design flexibility.
   - Distance-based Binary Backsc. (DBB) i.e., $\beta_i = 1$ if $d_i \geq \Delta$, otherwise $\beta_i = 0$.
   - Probabilistic Binary Backsc. (PBB) i.e., probability p in backsc. mode; probability $(1-p)$ remain silent.

4. **Harvesting-Target Backscattering (HTB)**; a minimum harvested energy from the retrodirective component i.e., $\Gamma_i \geq 0$.
   - Power control problem (Foschini-Miljanic algorithm) i.e., $\beta_i(l+1) = \min\left(1, \frac{\Gamma_i \beta_i(l)}{Q^{\Phi}_{\mathbf{RE}}(\boldsymbol{\beta}(l), d_i)}\right)$

Retrodirective Energy Beamforming: Numerical Results

- $M = 500$, $\lambda = 0.01$, $f_c = 900$ MHz, $\alpha = 3$, $\sigma^2 = -150$ dBm, $\tau = 10^{-8}$ sec, $\xi = 2$ m, $\rho = 30$ m, and $\zeta = 1$.





- FB provides a performance that is close to the perfect beamforming
- DIB provides fairness among ERs.
- The percentage of the ERs that satisfy Γ decreases, as Γ and λ increase.
- HTB outperforms FB; performance gain increases as P_t increases.

Outline

Frequency-domain SWIPT Waveform Design

- Design of a SWIPT waveform in the frequency domain.
  - Energy tones are superimposed at the spectral nulls or/and low-power sub-bands that characterize the PSD of the information-bearing signal.
  - Consequently, the resulting interference is tolerable (i.e., below a threshold).

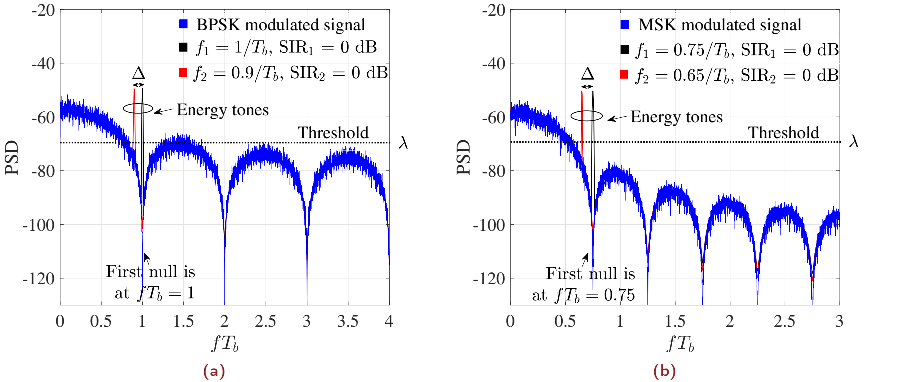


Figure: Power spectral density of the proposed FD-SWIPT waveforms, where BPSK and MSK signals are superimposed with a two-tones energy signal.

Experimental Validation

- Harvested energy vs. Tx-Rx distance for different number of energy tones; MSK modulation, TX gain 30 dB (20 dBm).

Hardware Configuration	Details
Computer	Hp Probook 16GB RAM
	Core i5 processor
SDR (TX and ID RX)	USRP-2920
RF energy harvester	Powercast P21XXCSR
Access point (WPT measurements)	Microchip MRF24J40
Experimental parameters	
RF carrier frequency	915 MHz
Sampling rate	1 MSamples/s

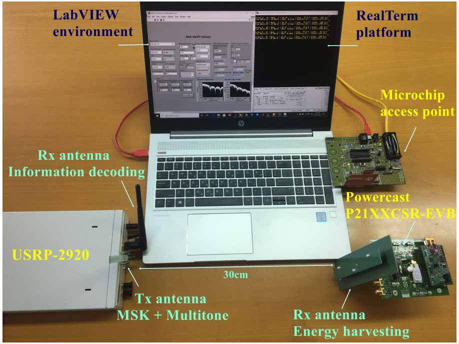


Figure: SDR-based testbed.

Experimental Validation

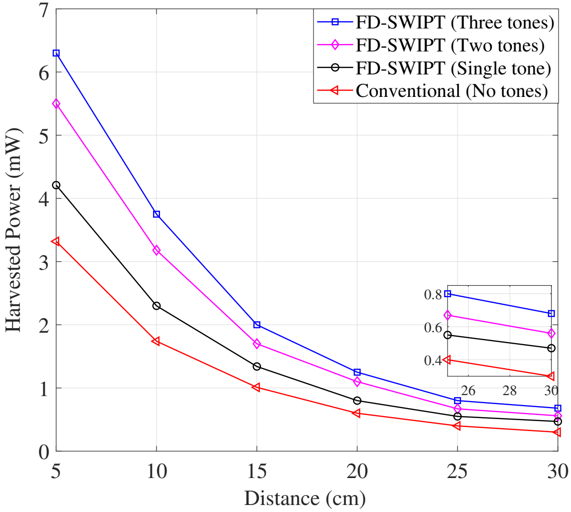


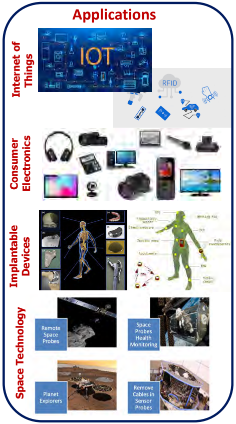
Figure: Harvested power vs. Tx-Rx distance for different number of energy tones.

Outline

Concluding Remarks

Information and Energy co-engineering and co-design.

- Smart Grids, Energy Harvesting, Green Radio, Power Line Communications etc.
- **Wireless Powered Communications**
  - Enabling technology, building block for the upcoming 6G wireless technologies.



Future Research Directions

1. Theoretical Advances
   - Mathematical models for various rectenna topologies (nonlinearities, memory).
   - Fundamental limits of WPC (non-linear wireless power channel).
   - Signal/waveform design for WPC systems.
   - New SWIPT architectures (no trade-off).
   - Safety issues (specific absorption rate, maximum permissible exposure).
2. Applications of interest
   - Wireless sensor networks/machine-type communications.
   - Wireless powered backscatter communications.
   - 6G networks (ultra densification, massive MIMO, Intelligent reflected surfaces).
3. Hardware Implementations
   - Energy receivers/Rectenna designs.
   - Implementation/proof of concept for SWIPT.
4. Machine Learning for WPC
   - Mathematical models are too simplistic e.g., impedance mismatching, parasitic effects, frequency/intermodulation product (IM2), etc. $\rightarrow$ Deep Learning.
   - SWIPT system as an autoencoder (Tx/Rx are implemented as DNNs).

References (1)

- R. Morsi, "Analysis and design of communication systems with wireless power transfer," Ph.D. thesis, Friedrich-Alexander University Erlangen-Nurnberg, Germany, 2020.
- I. Krikidis, "Wireless power transfer under Kullback-Leibler distribution uncertainty: A mathematical framework," *IEEE Wireless Commun. Lett.*, June 2020.
- I. Krikidis, S. Timotheou, S. Nikolaou, G. Zheng, D. W. K. Ng, and R. Schober, "Simultaneous wireless information and power transfer in modern communication systems," *IEEE Commun. Mag.*, vol. 52, pp. 104-110, Nov. 2014.
- L. R. Varshney, "Transporting information and energy simultaneously," in *Proc. IEEE Int. Symp. Inf. Theory*, Toronto, ON, Canada, July 2008, pp. 1612–1616.
- R. Zhang and C. K. Ho, "MIMO broadcasting for simultaneous wireless information and power transfer," *IEEE Trans. Wireless Comm.*, vol. 12, pp. 1989–2001, May 2013.
- S. B. Amor, S. M. Perlaza, I. Krikidis, and H. V. Poor, "Feedback enhances simultaneous wireless information and energy transmission in multiple access channels," *IEEE Trans. Inf. Theory*, vol. 63, pp. 5244–5265, Aug. 2017.
- I. Krikidis, "Information-energy capacity region for SWIPT systems with power amplifier nonlinearity," in *Proc. IEEE Int. Symp. Inf. Theory*, Los Angeles, CA, June 2020.
- I. Krikidis and C. Psomas, "Tone-index multisine modulation for SWIPT," *IEEE Signal Process. Lett.*, vol. 26, pp. 1252–1256, Aug. 2019.
- I. Krikidis, "Retrodirective large antenna energy beamforming in backscatter multi-user networks," *IEEE Wireless Commun. Lett.*, vol. 7, pp. 678–681, Aug. 2018.
- S. Timotheou, I. Krikidis, G. Zheng, and B. Ottersten, "Beamforming for MISO Interference Channels with QoS and RF Energy Transfer," *IEEE Transactions on Wireless Communications*, vol. 13, pp. 2646-2658, May 2014.
- S. Timotheou, I. Krikidis, S. Karachontzitis, and K. Berberidis, "Spatial domain simultaneous information and power transfer for MIMO channels," *IEEE Trans. Wireless Commun.*, vol. 14, pp. 4115-4128, Aug. 2015.
- J. Zhang, G. Zheng, I. Krikidis, and R. Zhang, "Specific absorption rate-aware beamforming in MISO downlink SWIPT systems," *IEEE Trans. Commun.*, vol. 68, pp. 1312–1326, Feb. 2020.

References (2)

- I. Krikidis, “Opportunistic beamforming with wireless powered 1-bit feedback through rectenna array”, *IEEE Signal Process. Lett.*, vol. 22, pp. 2054-2058, Nov. 2015.
- C. Psomas and I. Krikidis, “A wireless powered feedback protocol for opportunistic beamforming using rectenna arrays,” *IEEE Trans. Green Commun. Netw.*, vol. 2, pp. 100–113, Mar. 2018.
- I. Krikidis, “Simultaneous Information and Energy Transfer in Large-Scale Networks with/without Relaying,” *IEEE Trans. Commun.*, vol. 62, pp. 900-912, Mar. 2014.
- C. Psomas and I. Krikidis, “Successive interference cancellation in bipolar ad hoc networks with SWIPT,” *IEEE Wireless Commun. Lett.*, vol. 5, pp. 364–367, Aug. 2016.
- E. Demarchou, C. Psomas, and I. Krikidis, “Asynchronous ad hoc networks with wireless powered cognitive communications,” *IEEE Trans. Cognitive Commun. Netw.*, vol. 5, pp. 440–451, June 2019.
- I. Krikidis, S. Sasaki, S. Timotheou, and Z. Ding, “A low complexity antenna switching for joint wireless information and energy transfer in MIMO relay channels,” *IEEE Transactions on Communications*, vol. 62, pp. 1577-1587, May 2014.
- Z. Ding, I. Krikidis, B. Sharif and H. V. Poor, “Wireless information and power transfer in cooperative networks with spatially random relays,” *IEEE Trans. Wireless Commun.*, vol. 13, pp. 4440-4453, Aug. 2014.
- I. Krikidis, “Relay selection in wireless powered cooperative networks with energy storage,” *IEEE J. Sel. Areas Commun.*, vol. 33, pp. 2596–2610, Dec. 2015.
- M. Mohammadi, B. K. Chalise, H. A. Suraweera, C. Zhong, G. Zheng, and I. Krikidis, “Throughput analysis and optimization of wireless-powered multiple antenna full-duplex relay systems,” *IEEE Trans. Commun.*, vol. 64, pp. 1769–1785, Apr. 2016.
- C. Psomas and I. Krikidis, “Energy beamforming in wireless powered mmWave sensor networks,” *IEEE J. Sel. Areas Commun.*, vol. 37, pp. 424–438, Feb. 2019.
- C. Psomas and I. Krikidis, “Wireless powered mobile edge computing: Offloading or local computation?,” *IEEE Commun. Lett.*, July 2020

Wireless Powered Communications in the Era of 6G: A Bottom-up Multi-layer Approach

Thank you! Questions?

This work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 819819).

European Union
European Regional Development Fund

Κυπριακή Δημοκρατία

This work was co-funded by the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation, under the project INFRASTRUCTURES/1216/0017 (IRIDA)

on models and techniques for **massive access** in wireless **uplink** and **downlink**

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PAINLESS 4th Summer School @ Athens, May 9, 2022

outline

massive uplink access

model with a
common alarm message

user identification
in unsourced access

massive downlink ACK

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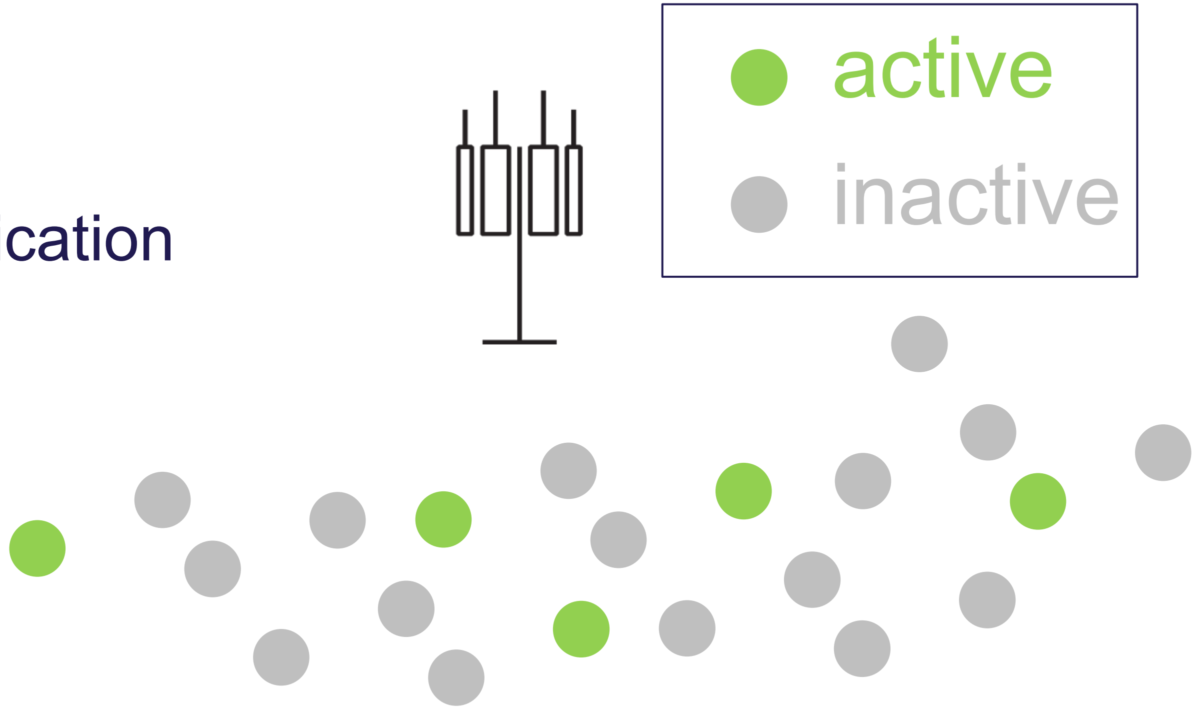
the massive access problem

mMTC:

massive Machine Type Communication



the set of nodes that
want to send to the BS in the uplink is unknown

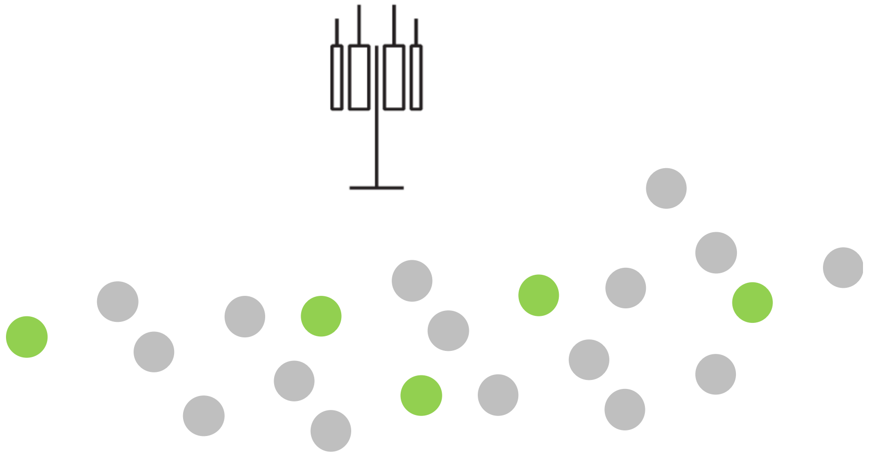
the massive access problem

quick assessment of the overhead

N nodes, K active

if N, K are known, then
the uncertainty is

$$\log_2 \binom{N}{K} \text{ [bits]}$$



maximized when $K = \frac{N}{2}$

however, mMTC works with assumption of sporadic, low-intensity access with $K \ll N$, pointing to

random access protocols

communication model

this is a slotted model

single BS received signal in the k −th slot:

$$y_k = \sum_{n=1}^{N} h_{kn} a_{kn} x_{kn} + z_k$$

N - total number of users;

h_{kn} - wireless channel coefficient during the k −th slot;

a_{kn} - the activity of n−th user during the k −th slot,
$a_{kn} = 1$ if the user is active and $a_{kn} = 0$ otherwise;

x_{kn} - packet/symbol sent by the n−th user during the k −th slot;

z_k - noise in the k −th slot.

sources of uncertainty

$$y_k = \sum_{n=1}^{N} h_{kn} a_{kn} x_{kn} + z_k$$

all of the following:

$$h_{kn}\ , a_{kn}, x_{kn}\ , z_k$$

the central role in mMTC is played by the uncertainty contained in the activity variable a_{kn}

sometimes the total number of active users $\sum_{n=1}^{N} a_{kn}$ can be assumed known or it can be estimated

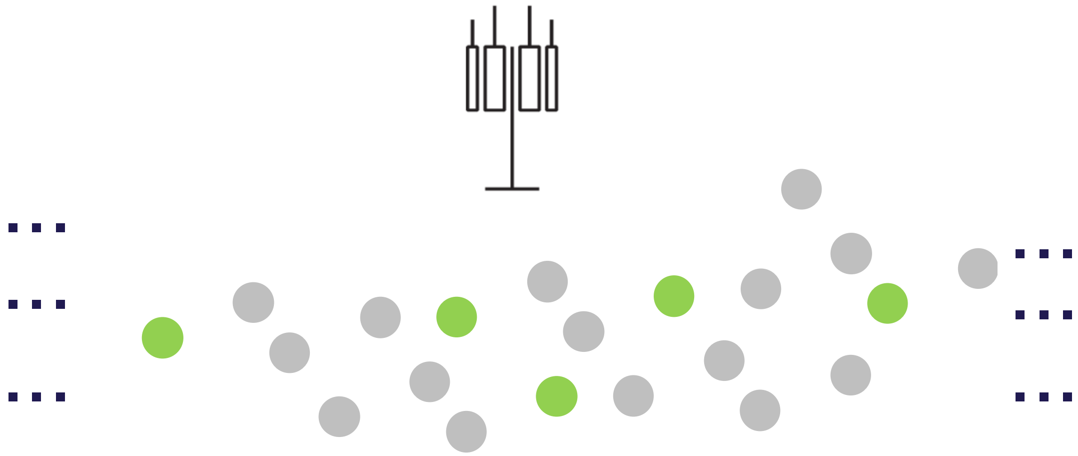
for modeling purpose we can make a_{kn}

- part of the channel $h'_{kn} = h_{kn} a_{kn}$, leading e.g. to Bernoulli-Gauss distribution for Rayleigh channel
- part of the transmitted symbol $x'_{kn} = x_{kn} a_{kn}$, leading to having a special ”empty” symbol.

random access: two classical assumptions

1. packet is an atomic unit of information

2. users are activated independently



packet as an atomic unit

convenient from the protocol viewpoint

used since the earliest days of ALOHA

infinite population assumption $N \to \infty$

allows asymptotic analysis

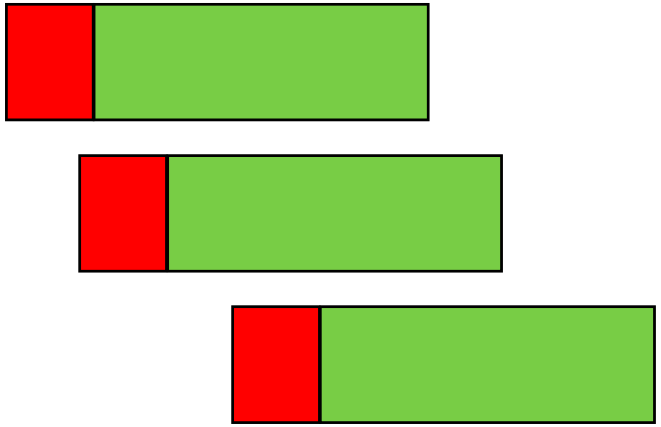
allows to model a ”once-in-a-lifetime” activation of a user, independent of the other users

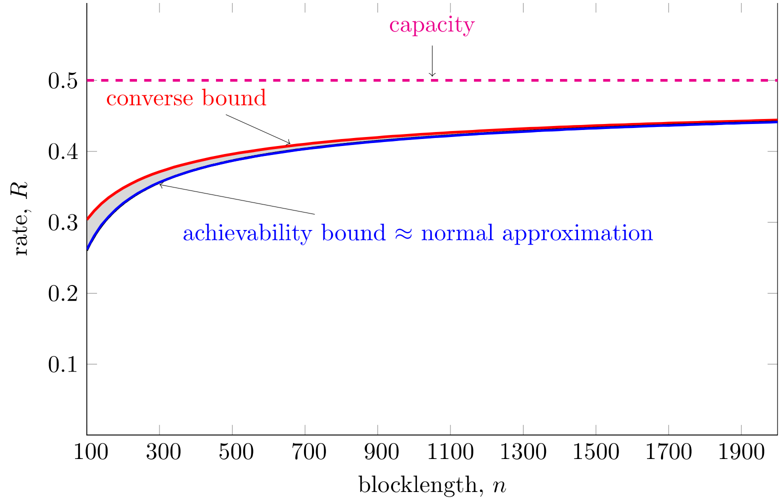
packet as an atomic unit

problems with the infinite population assumption

the packet cannot have a finite length
as the address size of a user $\log_2 N$ also goes to infinity.

finite blocklength effects in short packets





many-access channel (MnAC)

recent information-theoretic model suited for mMTC

$$Y = \sum_{k=1}^{\ell_n} S_k(w_k) + Z$$

each user accesses the channel independently with α_n

if not accessing, a special zero codeword is sent

if accessing, one of the M messages is sent

number of possible users l_n tied to the packet blocklength n

X. Chen, T. Y. Chen and D. Guo, "Capacity of Gaussian Many-Access Channels," in IEEE Transactions on Information Theory, vol. 63, no. 6, pp. 3516-3539, June 2017.

unsourced massive access (U-RA)

Gaussian MAC with $h_{kn} = 1$.

K active users

D non-zero messages

all users have one and the same codebook with D codewords

- no user identification possible!

an active user chooses its message uniformly at random, independently of any other user

decoding is done up to a permutation of transmitted messages

Y. Polyanskiy, "A perspective on massive random-access," 2017 IEEE International Symposium on Information Theory (ISIT), Aachen, 2017, pp. 2523-2527.

unsourced massive access (U-RA)

error defined from the perspective of a user

error occurs if the message is not decoded correctly
or more than one user sends the same message

finite blocklength limiting when the number of user is low,
multi-user interference when the number of users is high.

Y. Polyanskiy, "A perspective on massive random-access," 2017 IEEE International Symposium on Information Theory (ISIT), Aachen, 2017, pp. 2523-2527.

further developments in U-RA

U-RA gained importance as a model for massive IoT communciation

potential for significant spectral and power efficiency gains compared to other dedicated IoT-driven schemes such as LoRA and even LTE cellular systems (in terms of bit/s/Hz per sector) *.

however, eventual practical use of U-RA requires capability to identify and authenticate users.

- Alexander Fengler, Giuseppe Caire, Peter Jung, and Saeid Haghighatshoar, “Massive MIMO Unsourced Random Access”
- A. Vem, K. R. Narayanan, J.-F. Chamberland, and J. Cheng, “A user-independent successive interference cancellation based coding scheme for the unsourced random access Gaussian channel,” IEEE Transactions on Communications, vol. 67, no. 12, pp. 8258–8272, 2019.

random access: two classical assumptions

1. packet is an atomic unit of information

2. users are activated independently

a_n - the activity of n−th user during the contention round
$a_k = 1$ if the user is active and $a_k = 0$ otherwise;

ALOHA-type: $\Pr(a_1, a_2, a_3, \dots, a_N) = \prod_{i=1}^{N} \Pr(a_i)$

general activation pattern has a general joint distribution
$\Pr(a_1, a_2, a_3, \dots, a_N)$

outline

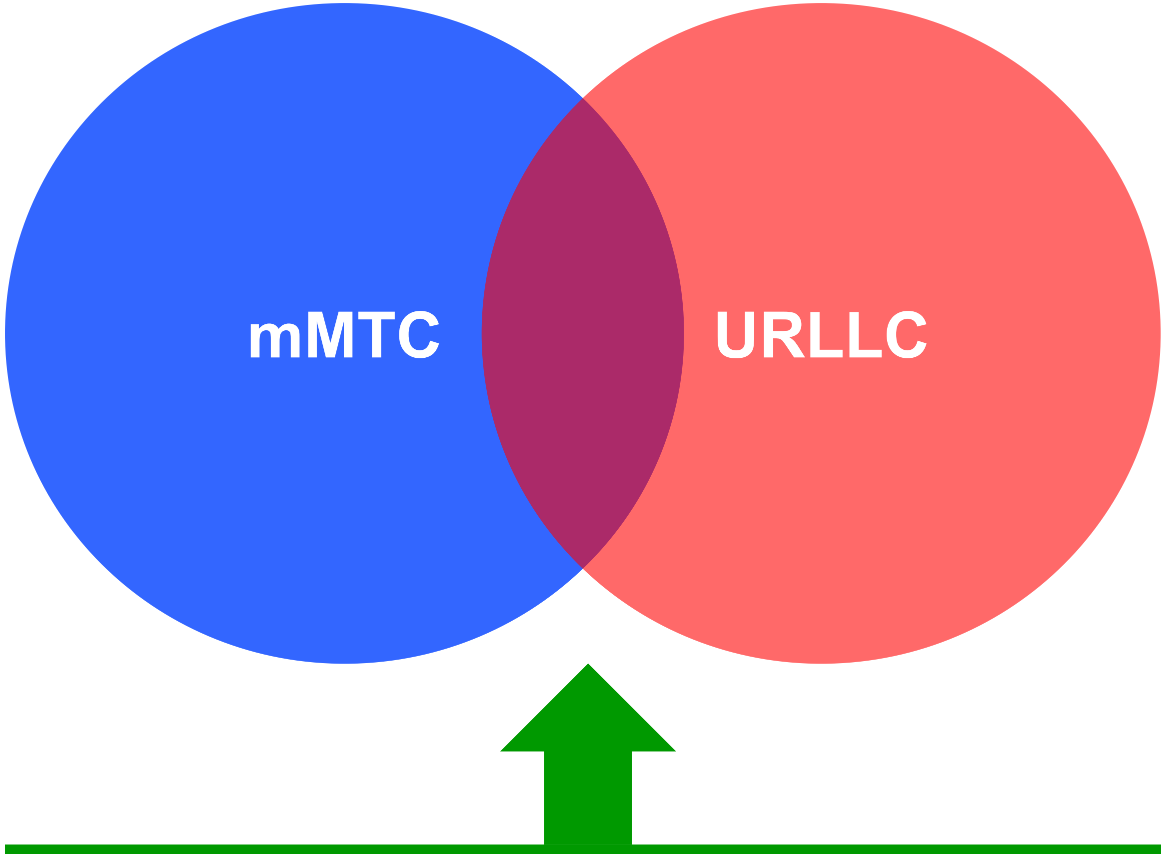
massive uplink access

model with a common alarm message

user identification in unsourced access

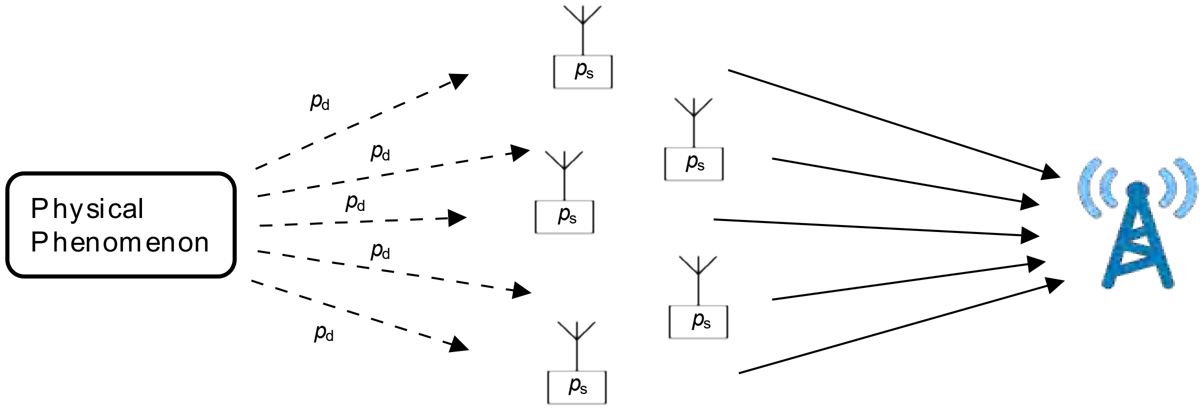
massive downlink ACK

simultaneous massive and ultra-reliable?



possible when the information across devices is correlated (e.g. alarm)

the scenario



a device generates two message types

individual update, independent of others

alarm-type message, correlated for all sensors

modeling the tradeoff between massive and ultra-reliable

the alarm set has M_a messages

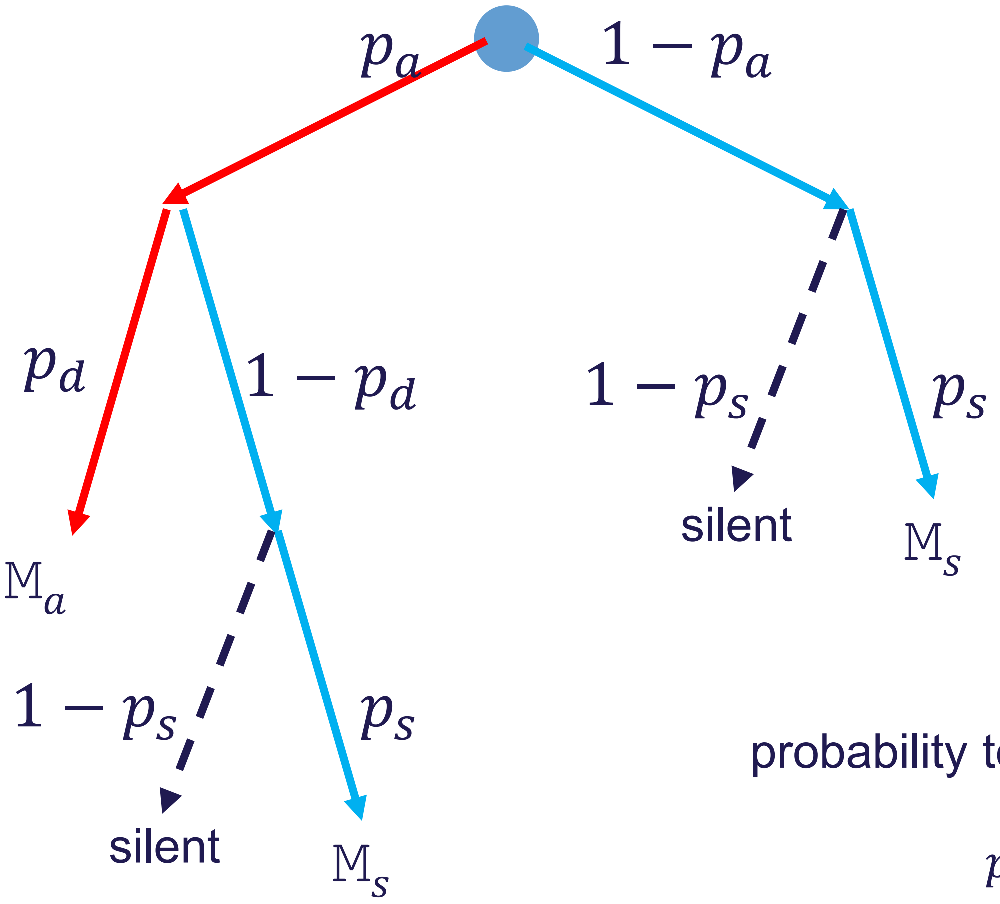
alarm occurs with probability p_a

when alarm occurs, the message to be sent
is chosen uniformly among the M_a messages

the same (common) alarm message
is sent by all nodes that detect it

a node detects alarm with probability p_d

modeling the tradeoff between massive and ultra-reliable



probability to send a standard message

$$p_s(1 - p_a p_d)$$

modeling the tradeoff between massive and ultra-reliable

there are in total N devices and K of them are active

example of low spectral efficiency
low p_s, high p_a and high p_d, $N = 10$ and $K = 9$
then most likely all nodes send the same alarm message
the information generated in this transmission is low

example of high spectral efficiency
high p_s, low p_a and p_d high, large N

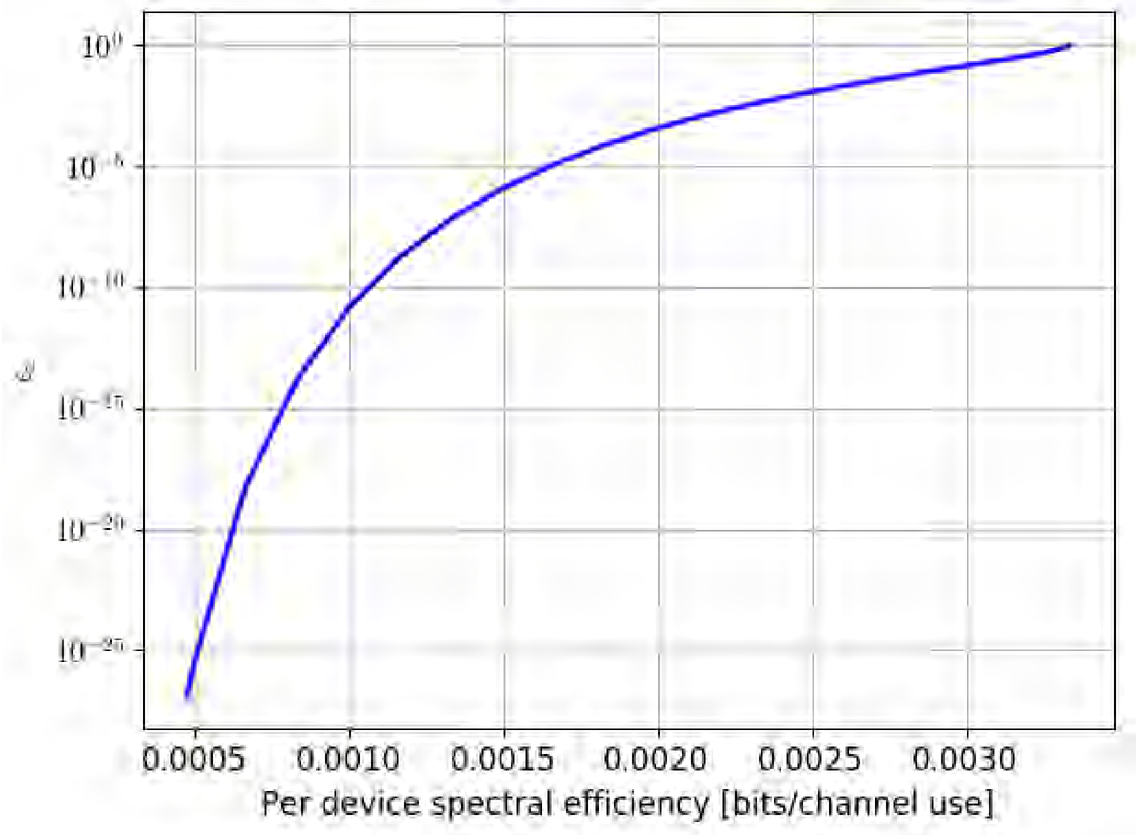
error events

the probability of error in alarm decoding
is much lower

error in standard message decoding occurs
if two devices send the same standard message

errors due to false positive needs to be taken into account

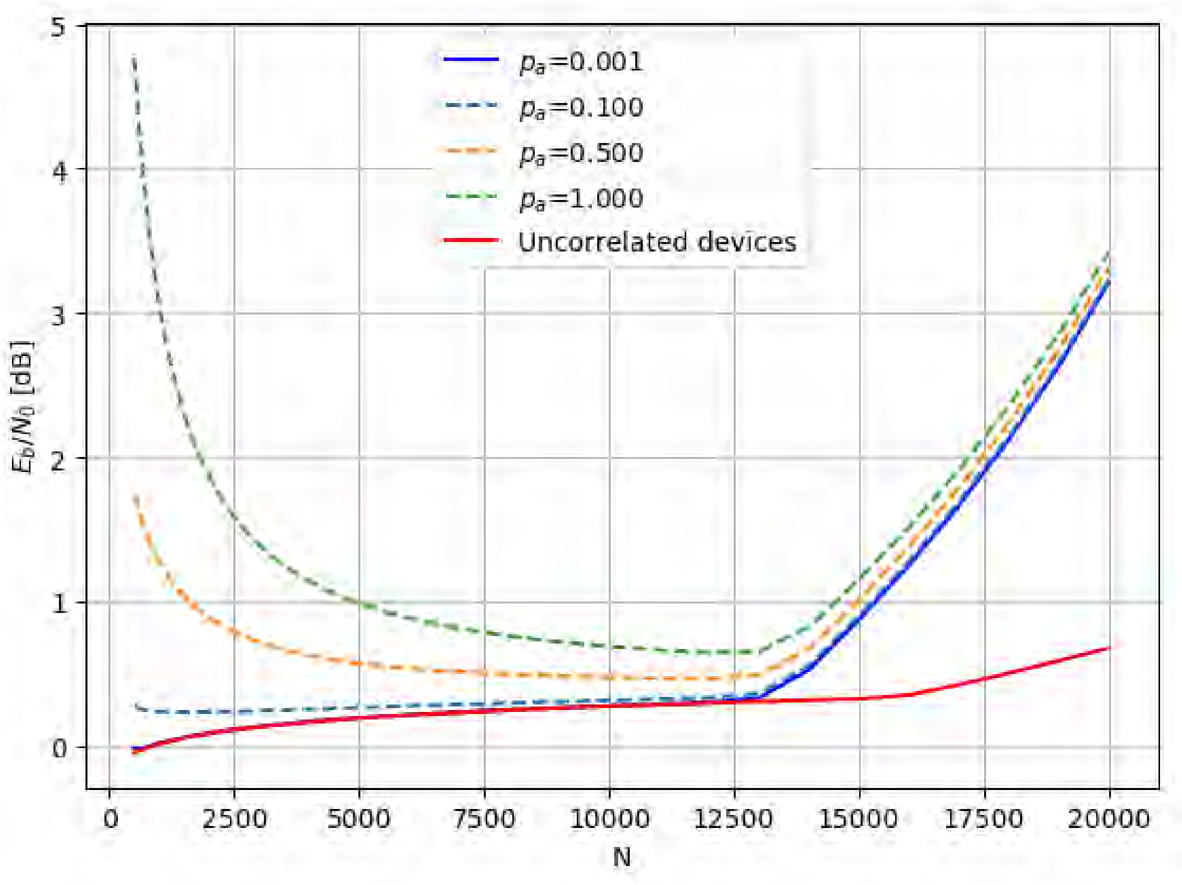
undetected alarm vs. spectral efficiency



Blocklength n = 30 000, N = 1000, target error probabilities $\varepsilon_s = 10^{-1}$, $\varepsilon_{fp} = 10^{-5}$,
message set sizes: standard message 100 bits, alarm message 3 bits. $p_s = 0.01$ and $p_a = 1$

We use p_d to control the spectral efficiency.

tradeoff EbN0 and number of devices



Blocklength n = 30 000, target error probabilities $\varepsilon_s = \varepsilon_{sa} = 10^{-1}$, $\varepsilon_{fp} = \varepsilon_a = 10^{-5}$,
message set sizes: standard message 100 bits, alarm message 3 bits. p_s =0.01, p_d is optimized

outline

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model with a
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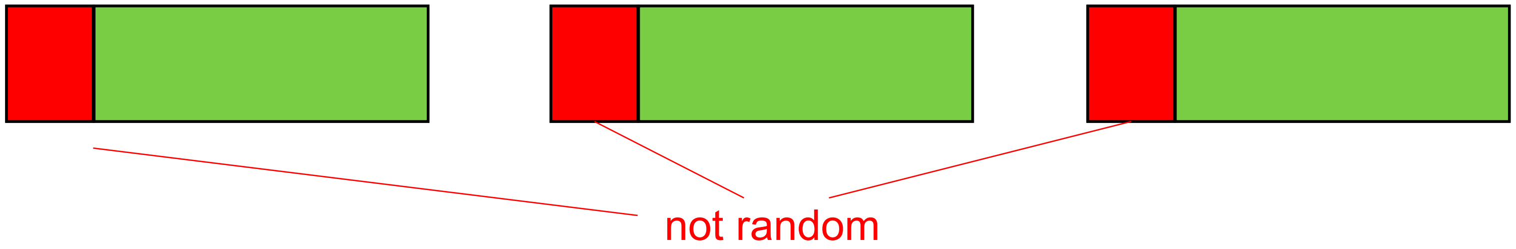
**user identification
in unsourced access**

massive downlink ACK

U-RA and identification

true unsourced random access requires that
the messages are independent and identically distributed across users

- this precludes the use of traditional address added to the packet.
- however, straightforward identification is not possible



objective

key idea for providing identification

we use a message authentication codes (MAC)
which is a function of the data and
a unique secret key assigned to each device

- this is enough to preserve the capability
  to identify and authenticate the devices reliably

the resulting packet structure allows to simplify the transmitters
and use less power at the cost of increased processing at the receiver

system model

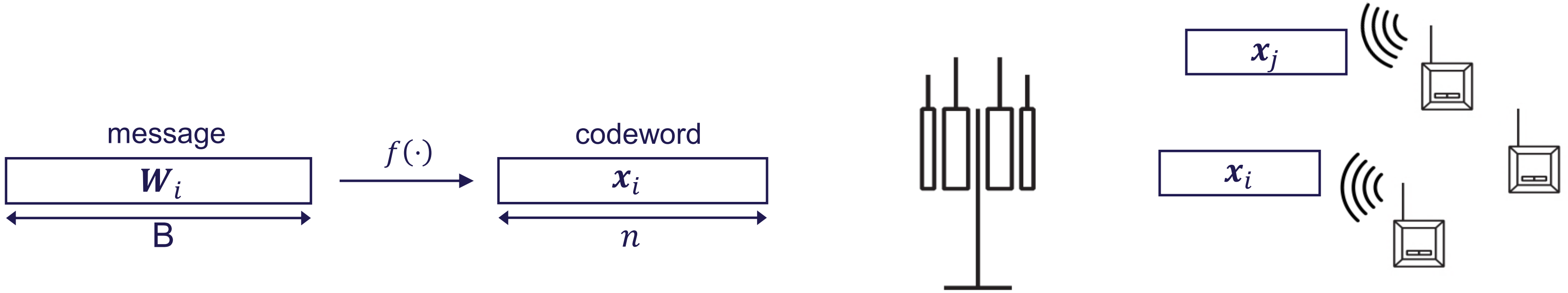
at each time slot K out of N users are active

users send messages $W_1, \ldots, W_K$
drawn independently and uniformly at random from a common set $\mathcal{M} = \{1, \ldots, M\}$

all users share the same encoder $f: [M] \to \mathcal{X}^n$
and use it to produce codewords $\boldsymbol{x}_1, \ldots, \boldsymbol{x}_K$, i.e. $\boldsymbol{x}_i = f(W_i)$

codewords are subject to power constraint $\|\boldsymbol{x}_i\|_2^2 \leq nP$, where n is the number of channel uses and P the average energy per channel use

transmission over a permutation-invariant, memoryless multiple access channel
$P_{Y|X^K}: \mathcal{X}^{n \times K} \to \mathcal{Y}^n$, i.e. $P_{Y|X^K}(\boldsymbol{y}|\boldsymbol{x}_1, \ldots, \boldsymbol{x}_K) = P_{Y|X^K}\left(\boldsymbol{y}|\boldsymbol{x}_{\pi(1)}, \ldots, \boldsymbol{x}_{\pi(K)}\right)$ for any $\boldsymbol{y} \in \mathcal{Y}^n$, $\boldsymbol{x}_1, \ldots, \boldsymbol{x}_K \in \mathcal{X}^{n \times K}$ and π



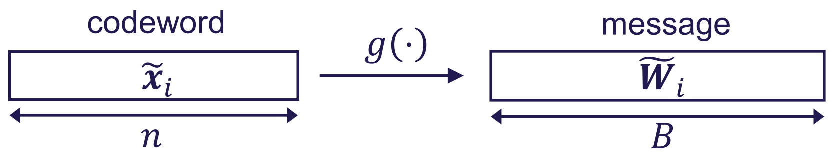
system model

at the base station the decoder $g: \mathcal{Y}^n \to [M]^K$ produces an unordered list of K messages

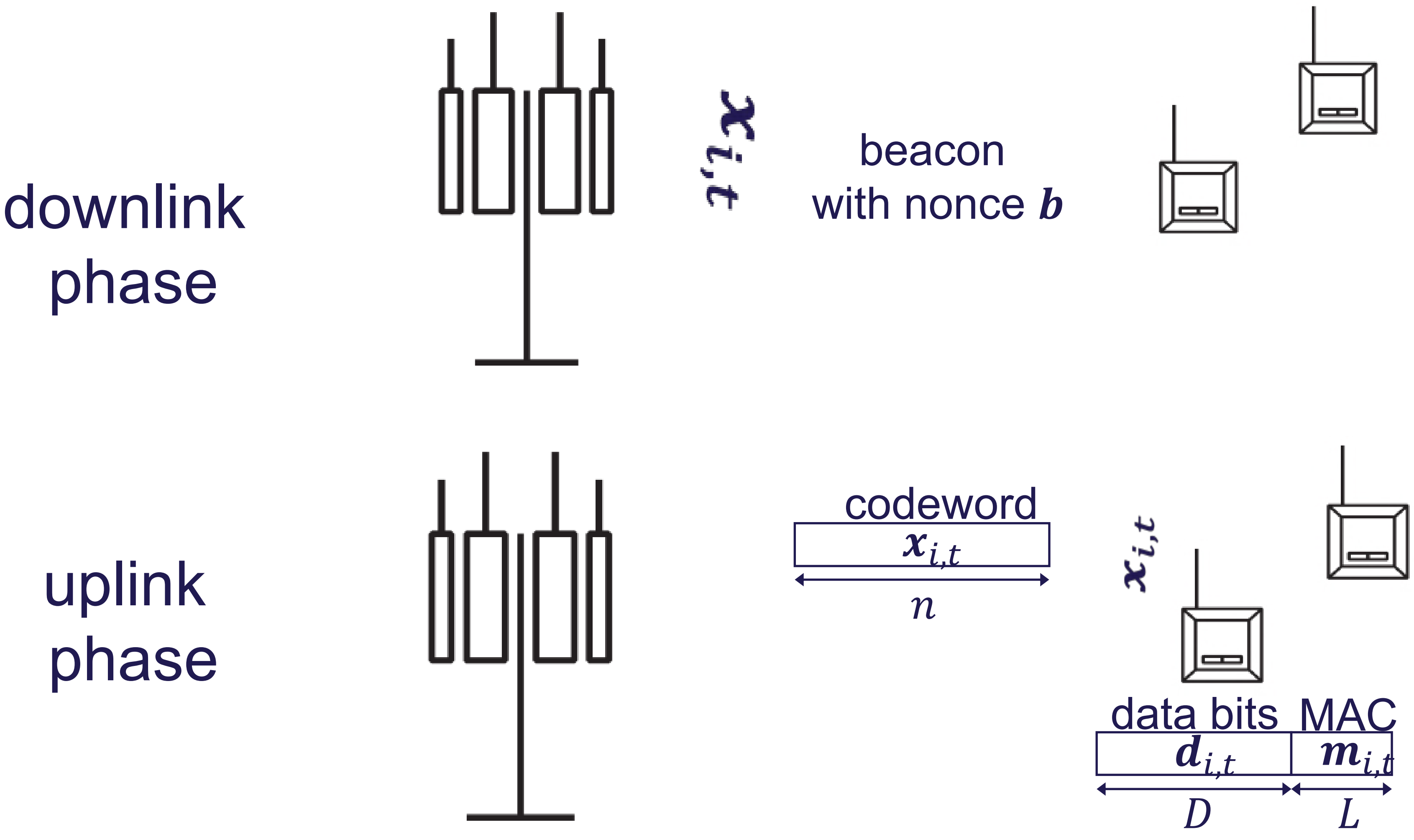
The K is fixed and it is assumed known to the base station

an error occurs whenever $g(\boldsymbol{y})$ does not contain a transmitted message, or if multiple users transmit the same message, i.e. $E_i = \{W_i \notin g(\boldsymbol{y})\} \cup \{W_i = W_j \ s.t. \, i \neq j\}$

- fixed K: for each error E_i, the list $g(\boldsymbol{y})$ contains a message which was not transmitted by any device
- these are false positives with probability of occurrence $P[E_i] = p_{FP}$



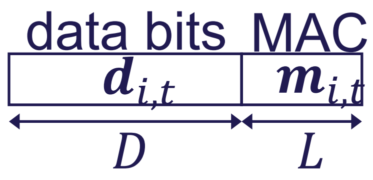
two-step protocol



operations at the user side

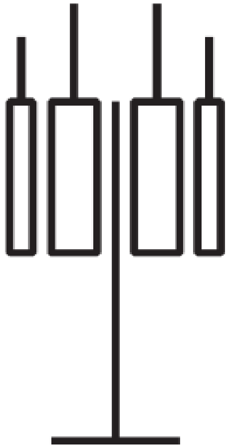
- the MAC $\boldsymbol{m}_i = \{0,1\}^L$ is generated by user i
  based on its data $\boldsymbol{d}_i \in \{0,1\}^D$ and its secret key $\boldsymbol{k}_i$, i.e. $\boldsymbol{m}_i = h(\boldsymbol{d}_i, \boldsymbol{k}_i, \boldsymbol{b})$
- the function h should be:
  computationally hard to invert and have low collision probability
- the nonce can be introduced to prevent replay attacks

MAC is appended to the data creating a complete message $W_i = [\boldsymbol{d}_i, \boldsymbol{m}_i]$



operations at the BS side

- the authenticity of the decoded message $\widetilde{W}_i = [\widetilde{\boldsymbol{d}}_i, \widetilde{\boldsymbol{m}}_i]$ is verified by recomputing the MAC and comparing it with the received one
- the BS tries different keys $\boldsymbol{k}$ to find a match
- since each key is a unique identifier of a device, finding a matching key provides an estimate of the identity of the sender



cryptographic errors

matching MAC is generated by a key
that does not belong to the actual sender

- the generated MAC might not be a unique identifier for the user
- the BS must generate many MACs with different secret keys
  to find the one that matches the one in the received packet

ideal MACs are assumed: the probability that a given (data, key) tuple produces a specific MAC of length L is $p = 2^{-L}$

- shorter MAC key leads to a higher probability of cryptographic errors

besides these errors, there are the usual transmission errors.

probability of cryptographic errors

type 1 error

- if the key of another user produces a match

$$p_{t1} = 1 - (1 - p)^{N-1}$$

where N is the number of users (keys).

type 2 error

- if the key of a user produces a valid MAC for more than one message

$$p_{t2} = 1 - (1 - p)^{K-1}$$

overall probability of successful authentication

$$p_{succ\_auth} = (1 - p_{t1})(1 - p_{t2}) = (1 - p)^{N+K-2}$$

other types of errors

authentication of a false positive:

the unsourced decoder produces a message not transmitted by anyone

- no keys match leading to a detectable false positive

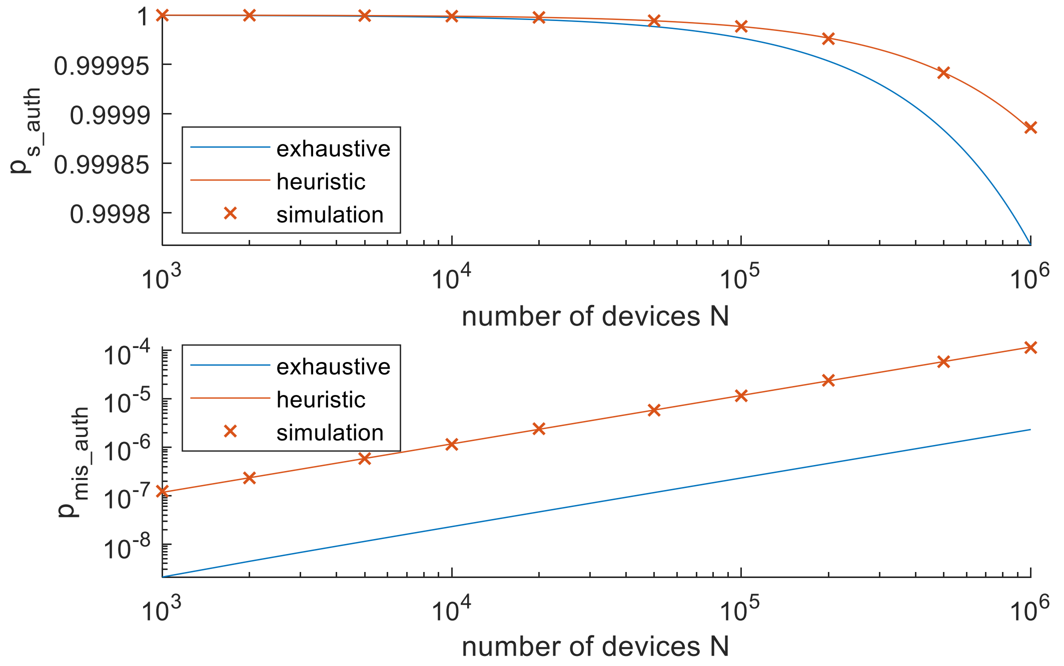
$$p_{d\_fp} = (1-p)^N$$

- exactly one key matches causing erroneous authentication

$$p_{fp\_auth} = (N - k_{TP})p(1-p)^{N+K-2}$$

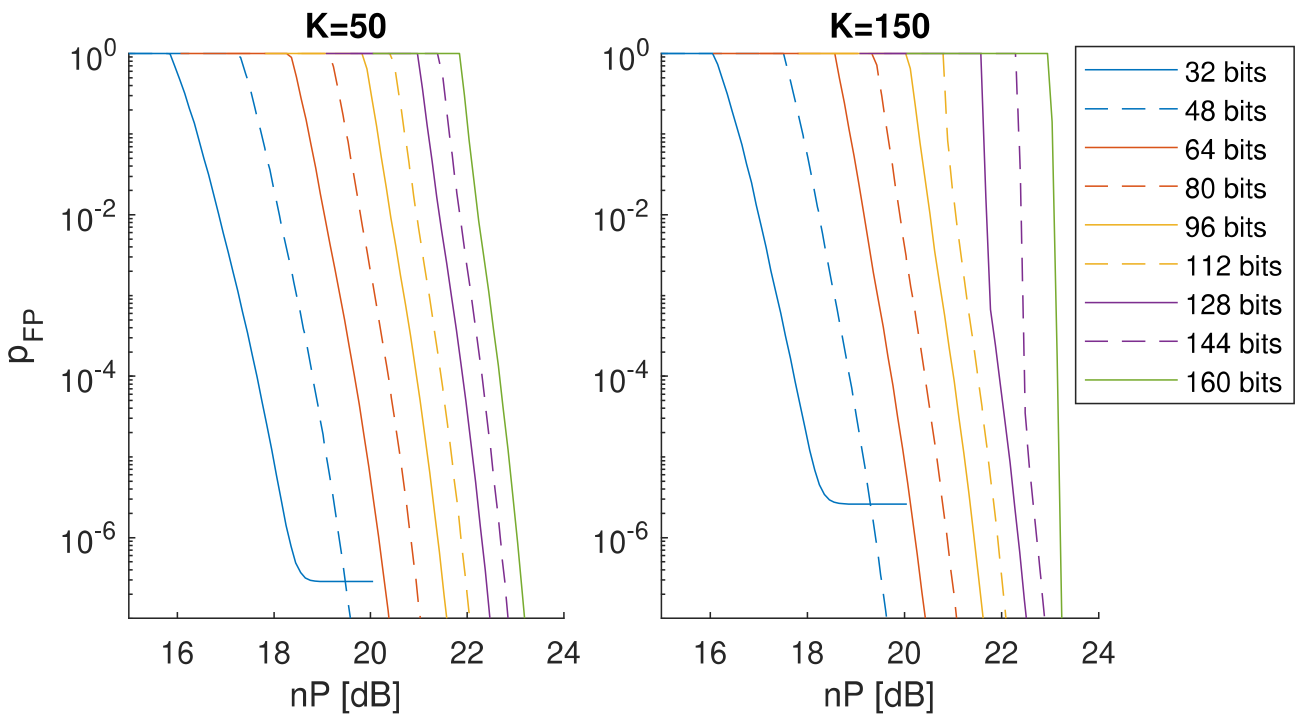
heuristic search

- the authenticator tries keys only until it finds a matching key
- cannot detect type 1 and type 2 errors
- the number of operations is on average reduced by half but at the cost of higher mis-authentication probability



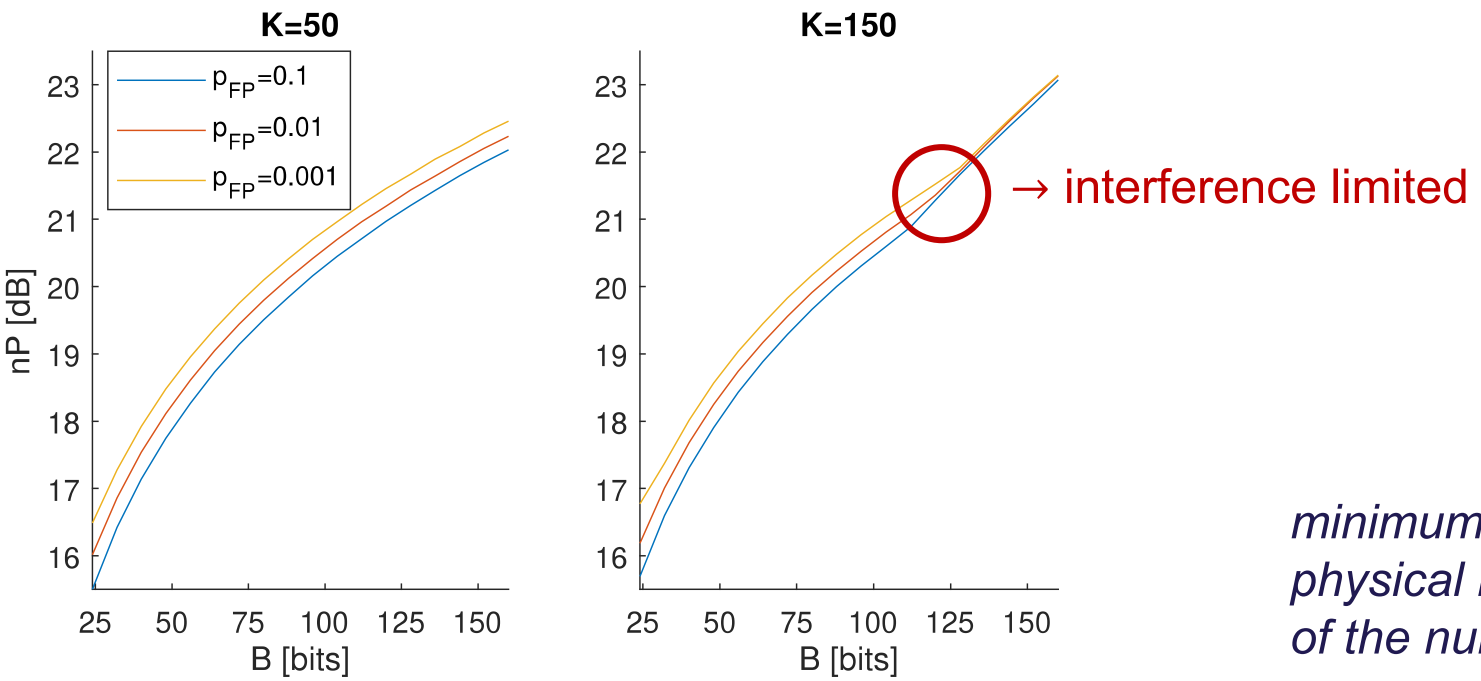
probability of successful authentication and probability of mis-authentication as a function of the total number of devices N. The number of messages is $K = 100$, $p_{FP} = 0.01$, MAC length $L = 32$ bits.

numerical illustration (1)



achievable physical layer error probability as a function of the energy per codeword and packet size B.

numerical illustration (2)



minimum energy required to achieve fixed physical layer error probability as a function of the number of information bits B

numerical illustration (3)

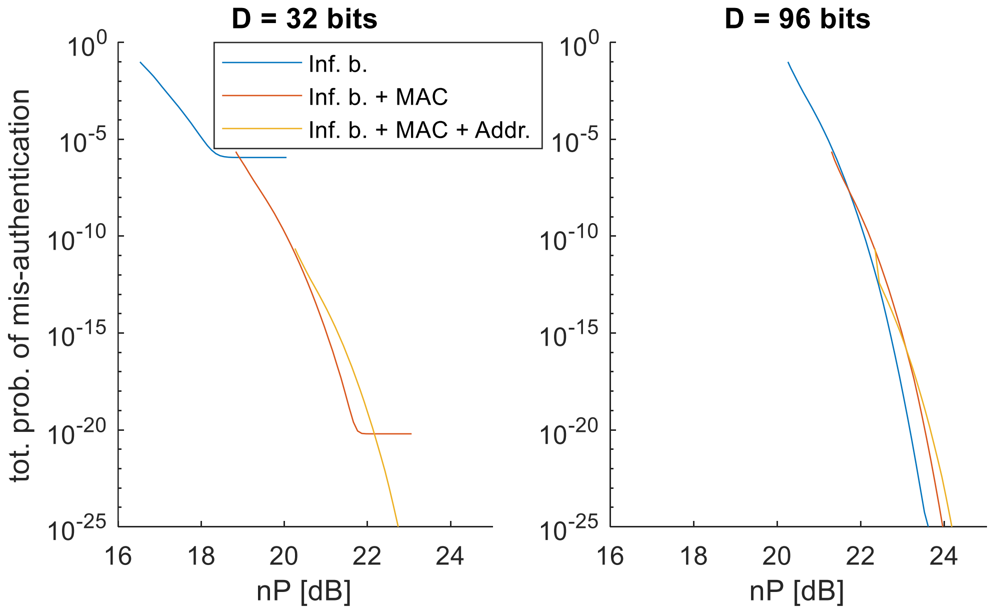
total error probability

- for a packet consisting of only data bits D
- in a proposed scheme where packet contains data and MAC, and the length is $D + L$
- for a classical packet structure that includes the address for a total of $D + L + A$ bits

$$p_{mis\_auth} = p_{FP}$$

$$p_{mis\_auth} = p_{FP} p_{fp\_auth}$$

$$p_{mis\_auth} = p_{FP} p$$



total probability of mis-authentication as a function of energy. The number of messages is $K = 100$ and $N = 10^5$, $L = A = 32$ bits

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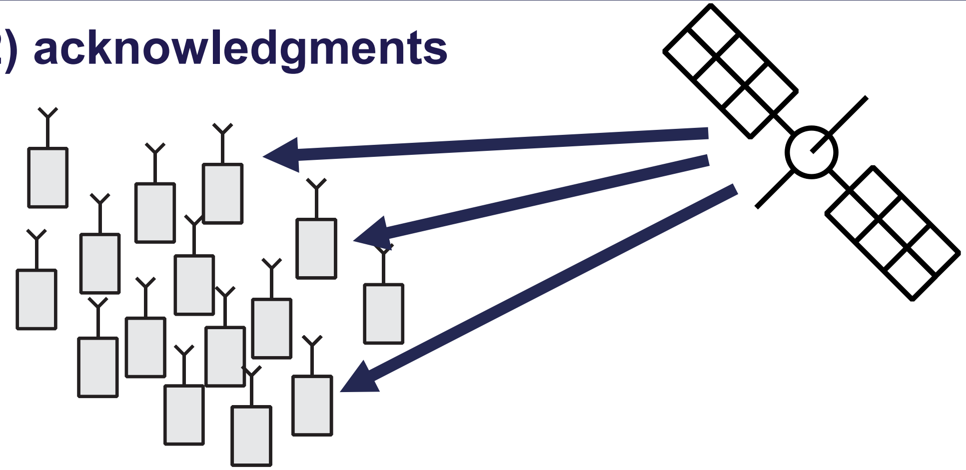
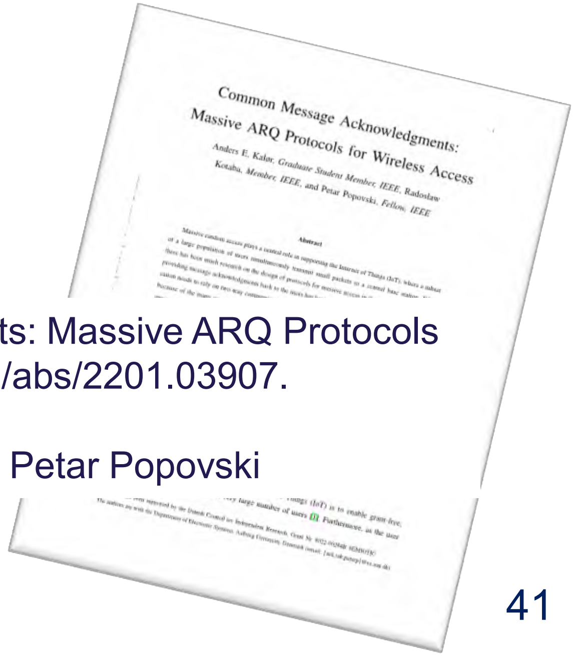
common acknowledgments



can we do better than concatenation?

user 65	user 103	user 211

what are the **limits** and **trade-offs**?



"Common Message Acknowledgments: Massive ARQ Protocols for Wireless Access," https://arxiv.org/abs/2201.03907.

joint work with Radoslaw Kotaba and Petar Popovski

formal problem definition

- $[N] = \{0,1,\ldots,N-1\}$: set of potentially active users (e.g., $N = 2^{64}$)
- $\mathcal{A}$: set of active users ($|\mathcal{A}| \ll N$)
- $\mathcal{S} = \{s_1, s_2, \ldots, s_K\}$: set of K ***recovered*** users
- K is constant ($K \ll N$, e.g., $\mathrm{K} = 100$)

encoder

$$f: \binom{[N]}{K} \to \{0,1\}^B$$

user *n*’s decoder

$$g_n: \{0,1\}^B \to \{0,1\}$$

message length

error types

false positives

$$\varepsilon_{\mathrm{fp}} = \mathbb{E}\left[\Pr\left(g_n\left(f(\mathcal{S})\right) = 1 \,\middle|\, n \in \mathcal{A} \setminus \mathcal{S}\right) \mid K\right]$$

false negatives

$$\varepsilon_{\mathrm{fn}} = \mathbb{E}\left[\Pr\left(g_n\left(f(\mathcal{S})\right) = 0 \,\middle|\, n \in \mathcal{S}\right) \mid K\right]$$

depend only on the **active** users ($s_k \in \mathcal{A}$), and not the **inactive** users

error-free encoding

i.e., $\varepsilon_{\text{fp}} = \varepsilon_{\text{fn}} = 0$

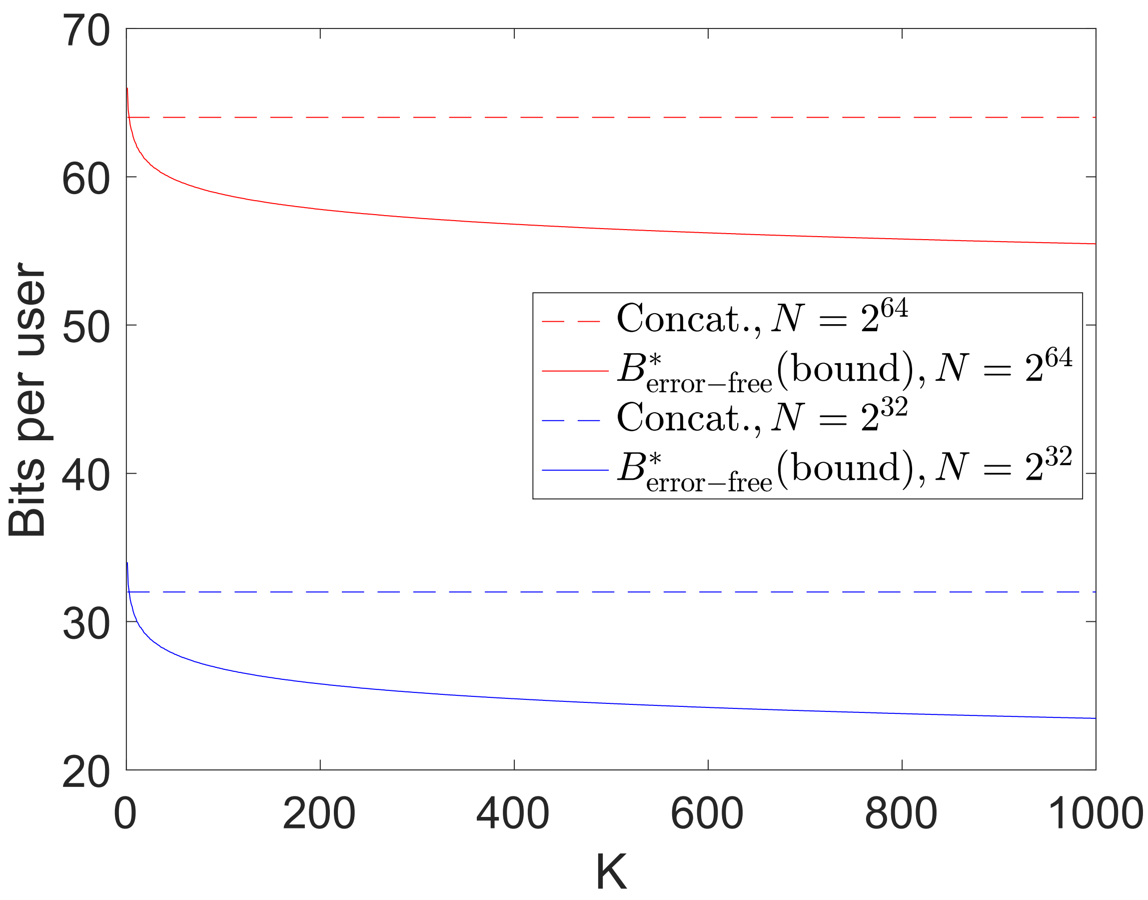
there are $\binom{N}{K}$ ways to pick the K recovered users, so we need

$$B^*_{\text{error-free}} = \left\lceil \log_2 \binom{N}{K} \right\rceil \quad \text{[bits]}$$

$$\geq \left\lceil \text{K} \log_2 \left(\frac{N}{K} \right) \right\rceil \quad \text{[bits]}$$

error-free encoding

note that $B^*_{\text{error-free}} = \left\lceil \log_2 \binom{N}{K} \right\rceil \leq \left\lceil \mathrm{K} \log_2 \left(\frac{Ne}{K} \right) \right\rceil$ bits

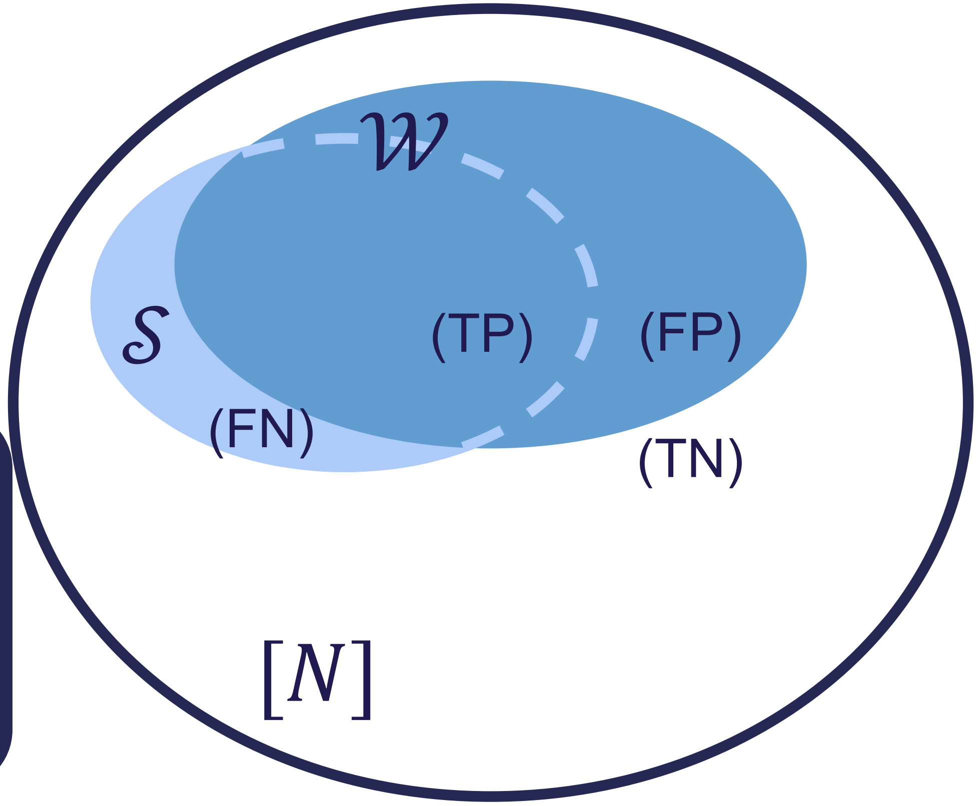


encoding with errors

i.e., $\varepsilon_{\text{fp}} > 0,\ \varepsilon_{\text{fn}} \geq 0$

each message $\mathcal{W}$ can be used for several sets $\mathcal{S}$

$$B^*_{\text{fp,fn}} \geq K \log_2\left(\frac{1}{\varepsilon_{\text{fp}} + \frac{K}{N}}\right) - K \log_2\left(\frac{e}{1-\varepsilon_{\text{fn}}}\right) - \varepsilon_{fn} K \log_2\left(\frac{1-\varepsilon_{\text{fn}}}{\varepsilon_{\text{fn}}\left(\varepsilon_{\text{fp}} + \frac{K}{N}\right)}\right) - \log_2 K \text{ [bits]}$$



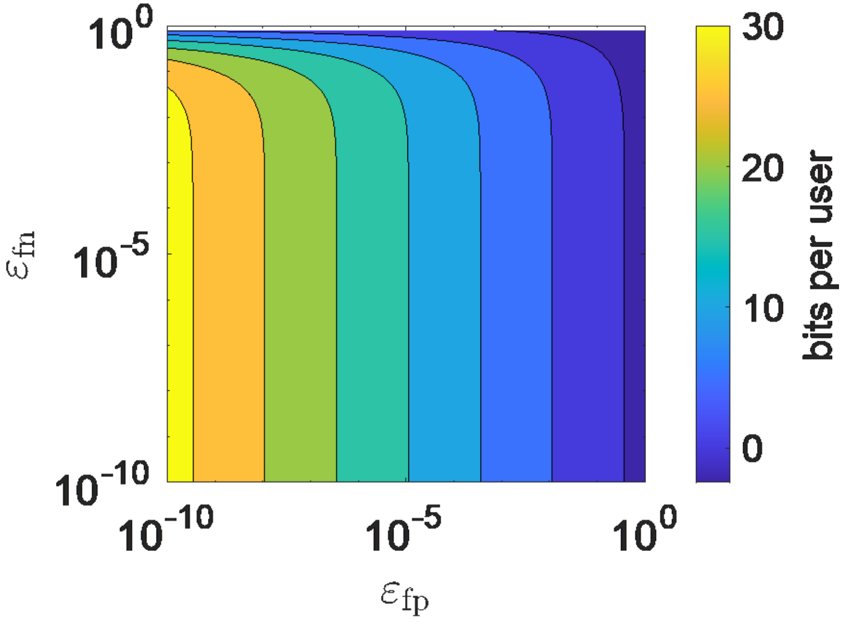
R. Pagh and F. F. Rodler, "Lossy dictionaries," in *Eur. Symp. Algorithms*. Springer, 2001, pp. 300–311

encoding with errors

does not depend on N as $N \to \infty$ for fixed K

$$B^*_{\mathrm{fp,fn}} \geq K \log_2\left(\frac{1}{\varepsilon_{\mathrm{fp}} + \frac{K}{N}}\right) - K \log_2\left(\frac{e}{1-\varepsilon_{\mathrm{fn}}}\right) - \varepsilon_{\mathrm{fn}} K \log_2\left(\frac{1-\varepsilon_{\mathrm{fn}}}{\varepsilon_{\mathrm{fn}}\left(\varepsilon_{\mathrm{fp}} + \frac{K}{N}\right)}\right) - \log_2 K$$

false positives give the highest gains

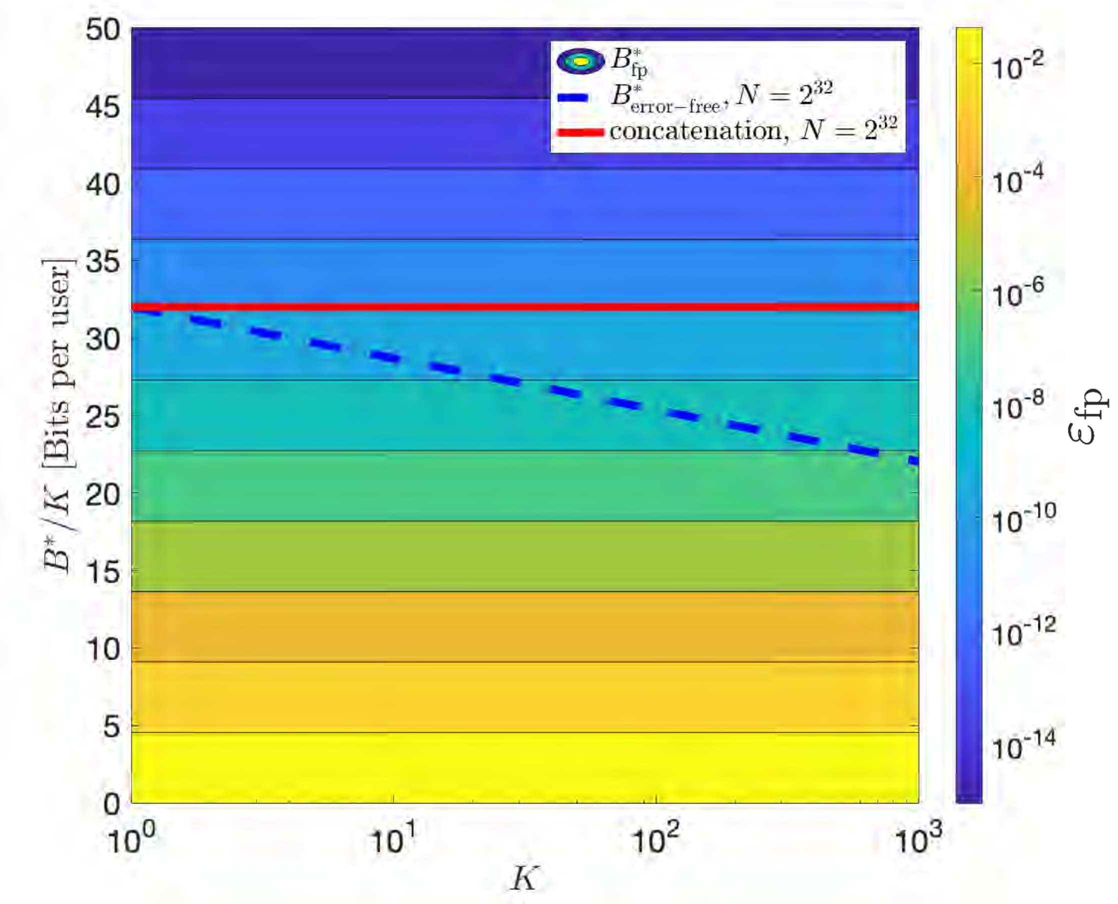


encoding with errors, $\varepsilon_{\text{fn}} = 0$

i.e., $\varepsilon_{\text{fp}} > 0,\ \varepsilon_{\text{fn}} = 0$

for large N:

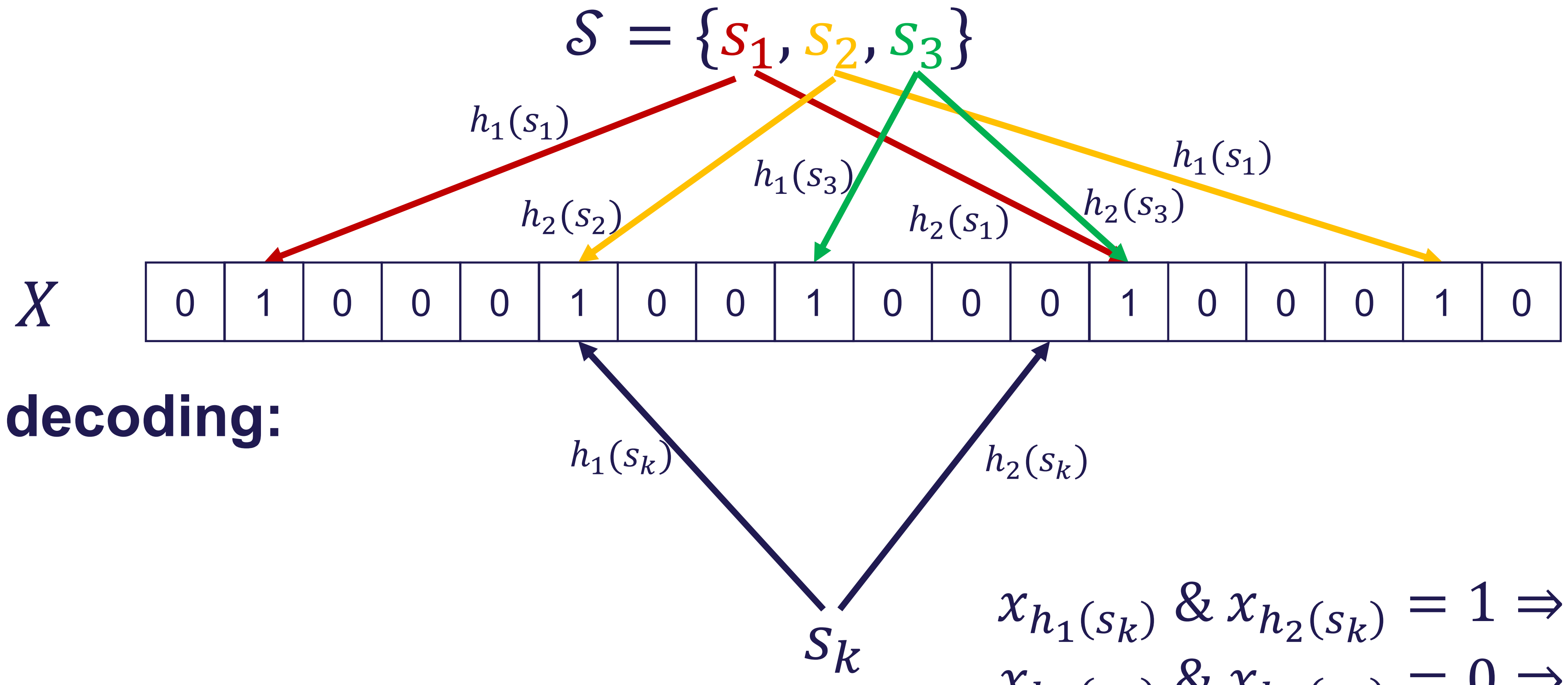
$$B^*_{\text{fp}} = K \log_2\left(\frac{1}{\varepsilon_{\text{fp}}}\right) \pm \mathcal{O}(\log\log N)$$



L. Carter, et al., “Exact and approximate membership testers,” in Proc. Tenth annu. ACM Symp. Theory Comp. (STOC). ACM Press, 1978.
M. Dietzfelbinger and R. Pagh, “Succinct data structures for retrieval and approximate membership,” in Int. Colloq. Automata, Languages, and Program. Springer, 2008, pp. 385–396.

Bloom filter

encoding:



decoding:

$$x_{h_1(s_k)} \,\&\, x_{h_2(s_k)} = 1 \Rightarrow s_k \in \mathcal{S}$$
$$x_{h_1(s_k)} \,\&\, x_{h_2(s_k)} = 0 \Rightarrow s_k \notin \mathcal{S}$$

linear equations

consider the set of K linear equations constructed using hashes of the user ids

$$\mathcal{S} = \{s_1, s_2, s_3\}$$

$$\begin{bmatrix} h_1^{(1)}(s_1) & h_1^{(2)}(s_1) & h_1^{(3)}(s_1) \\ h_1^{(1)}(s_2) & h_1^{(2)}(s_2) & h_1^{(3)}(s_2) \\ h_1^{(1)}(s_3) & h_1^{(2)}(s_3) & h_1^{(3)}(s_3) \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} h_2(s_1) \\ h_2(s_2) \\ h_2(s_3) \end{bmatrix}$$

unknown vector

All hash functions are
$[N] \to \mathrm{GF}(2^p)$

M. Dietzfelbinger and R. Pagh, “Succinct data structures for retrieval and approximate membership,” in *Int. Colloq. Automata, Languages, and Program.* Springer, 2008, pp. 385–396.
E. Porat, “An optimal bloom filter replacement based on matrix solving,” in Int. Comput. Sci. Symp. Russia. Springer, 2009, pp. 263–273.

linear equations

$$\begin{bmatrix} h_1^{(1)}(s_1) & h_1^{(2)}(s_1) & h_1^{(3)}(s_1) \\ h_1^{(1)}(s_2) & h_1^{(2)}(s_2) & h_1^{(3)}(s_2) \\ h_1^{(1)}(s_3) & h_1^{(2)}(s_3) & h_1^{(3)}(s_3) \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} h_2(s_1) \\ h_2(s_2) \\ h_2(s_3) \end{bmatrix}$$

All hash functions are
$[N] \to \mathrm{GF}(2^p)$

decoding:

$$h_1^{(1)}(s_k) z_1 + h_1^{(2)}(s_k) z_2 + h_1^{(3)}(s_k) z_3 = h_2(s_k) \Rightarrow s_k \in \mathcal{S}$$

all we need to send is $[z_1 \quad z_2 \quad z_3]^T$

Kp bits

$$\varepsilon_{\mathrm{fp}} = 2^{-p} \Leftrightarrow p = \left\lceil \log_2\left(\frac{1}{\varepsilon_{\mathrm{fp}}}\right) \right\rceil$$

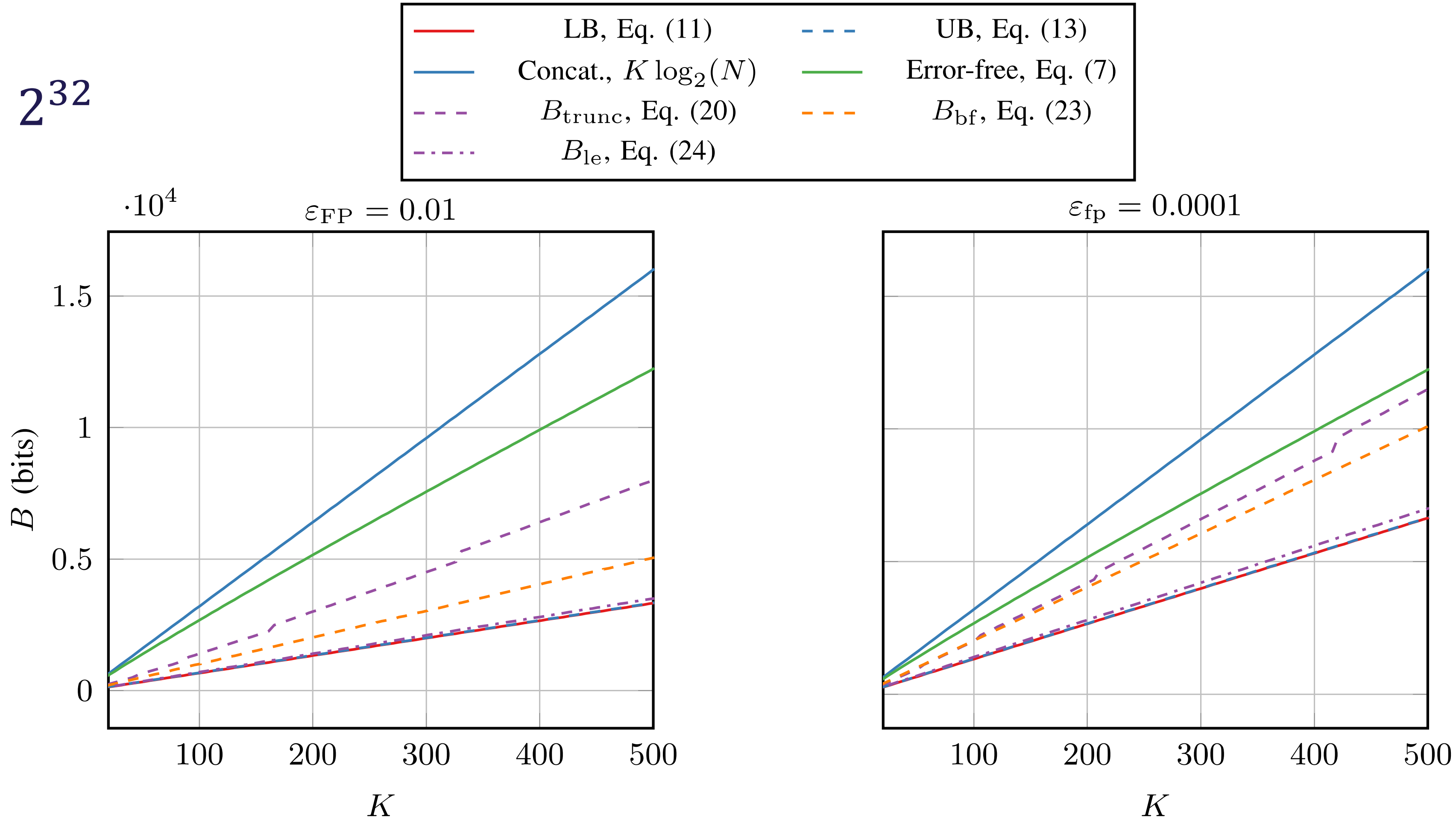
recall the bound:

$$B_{\mathrm{fp}}^* = K \log_2\left(\frac{1}{\varepsilon_{\mathrm{fp}}}\right) \pm \mathcal{O}(\log\log N)$$

M. Dietzfelbinger and R. Pagh, “Succinct data structures for retrieval and approximate membership,” in *Int. Colloq. Automata, Languages, and Program.* Springer, 2008, pp. 385–396.
E. Porat, “An optimal bloom filter replacement based on matrix solving,” in Int. Comput. Sci. Symp. Russia. Springer, 2009, pp. 263–273.

comparison

$N = 2^{32}$



random K

we assume that K is included in the feedback packet (small additional cost)

	variable-length ACK coding	fixed-length ACK coding
packet length	variable	constant
$\varepsilon_{\mathbf{fp}}$	constant	variable

bounds in paper → variable

variable field order $GF\left(2^{\left\lceil \log_2\left(\frac{1}{\varepsilon_{\text{fp}}}\right)\right\rceil}\right)$ → variable

downlink erasure channel

encoder

$$f: \binom{[N]}{K} \to \{0,1\}^B$$

user *n*'s channel

$X \in \{0,1\}^B$ → X or e

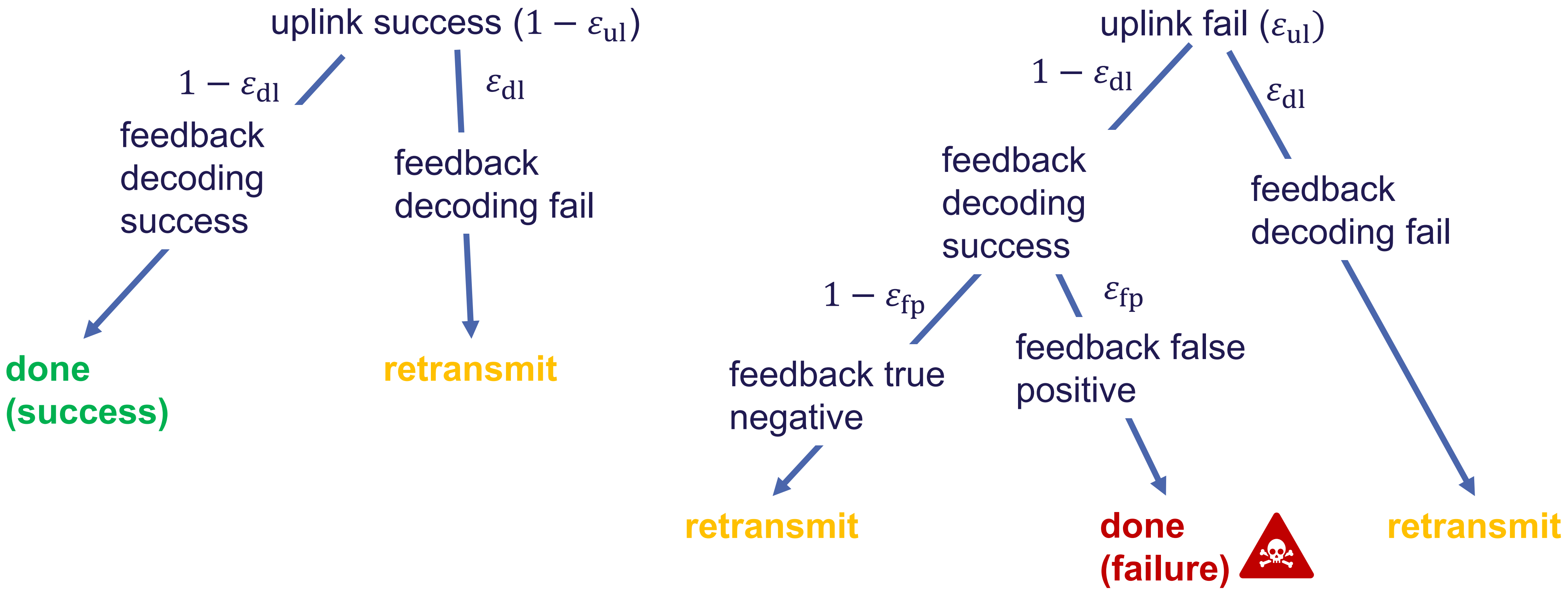
user *n*'s decoder

$$g_n: \{0,1\}^B \cup \mathrm{e} \to \{0,1\}$$

erasure probability assumed to be equal to the outage probability

for evaluation we will assume:
- fixed-length coding
- Poisson arrivals
- Rayleigh fading
- 2048 symbols
- 64 tx antennas

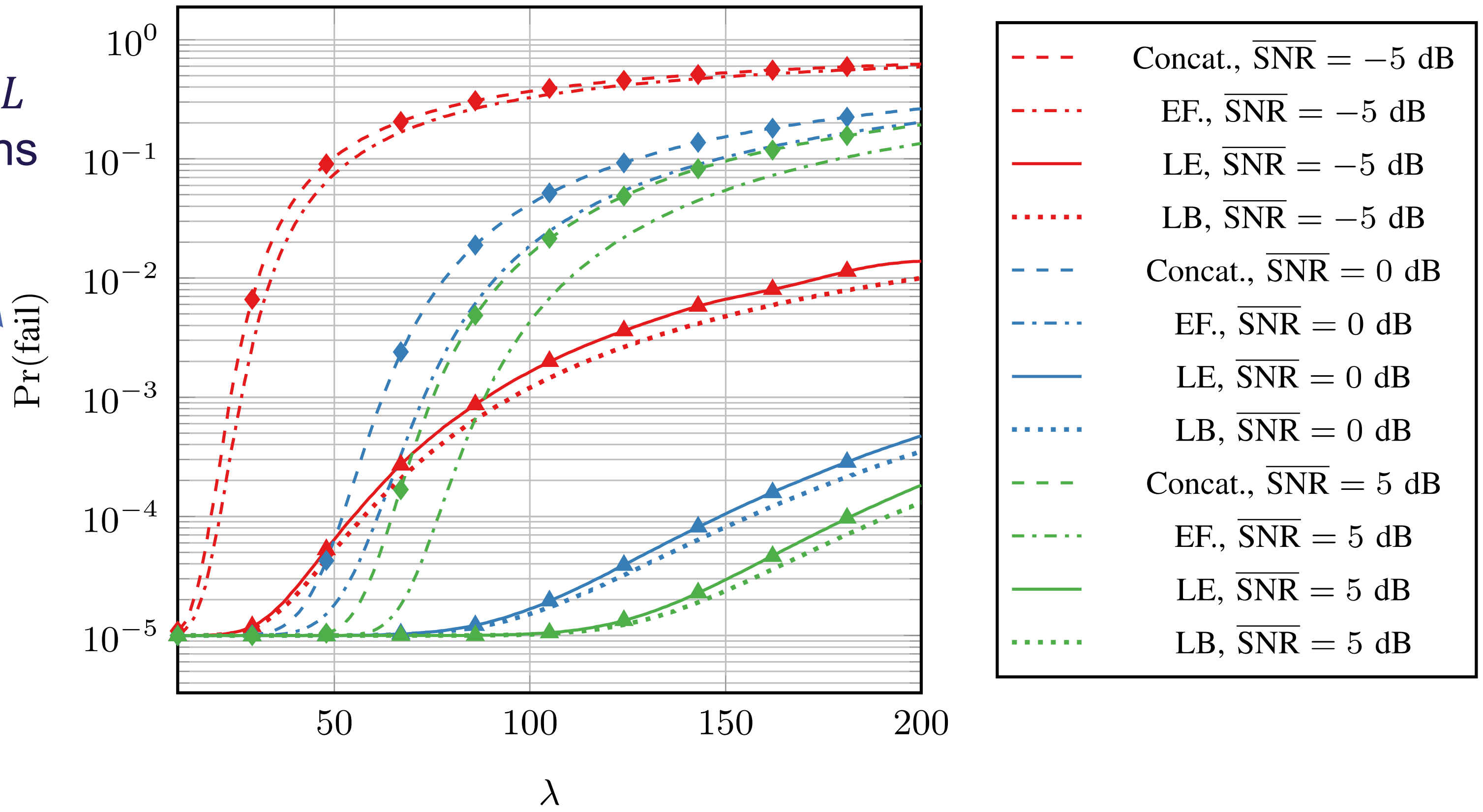
ARQ model



reliable feedback is a **trade-off** between **reliable transmission** and **false positive** probability

fixed-length feedback with fading

not in green state within L transmissions



- $L = 5$
- $\varepsilon_{\text{ul}} = 0.1$
- $K \sim \text{Poisson}(\lambda)$ (iid in each retransmission)
- Rayleigh fading
- 2048 symbols
- 64 tx antennas
- markers indicate simulations

- more **efficient coding** allows for **lower transmission rate**
- significanly **higher reliability** despite **false positives**

resolving failures

- some users erronously believe they succeeded when they fail
- false positives exist in all ARQ systems (CRC failures, etc.)
  - example: 16-bit CRC gives $\varepsilon_{\mathrm{fp}} \approx 1.5 \cdot 10^{-5}$
  - ACK messages are usually designed to have $\varepsilon_{\mathrm{fp}} \ll \varepsilon_{\mathrm{fn}}$, but we have assumed the opposite
- need to be resolved at higher layers, e.g., using sequence numbers

conclusion and outlook

- the rich area of massive access modeling
- mMTC and URLLC can converge when we look at the message content (common alarm)
- we have shown a method that makes unsourced access practical, with user identification and authentication
- feedback in massive random access seems to be an overlooked problem
  - counterintuitive solution with enforcing false positives

key references

- K. Stern, A. E. Kalør, B. Soret and P. Popovski, "Massive Random Access with Common Alarm Messages," 2019 IEEE International Symposium on Information Theory (ISIT), 2019
- R. Kotaba, A. E. Kalør, P. Popovski, I. Leyva-Mayorga, B. Soret, M. Guillaud, and L. Ordonez, "How to Identify and Authenticate Users in Massive Unsourced Random Access," vol. 25, no. 12, pp. 3795-3799, Dec. 2021
- A. E. Kalør et al., “Common Message Acknowledgments for Massive Random Access Scenarios”, available at https://arxiv.org/abs/2201.03907.

Future Smart Networks and Services

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Outline

- 5G and Beyond Vision and Services
- Proposed 5G and Beyond Architecture
  - Optical Networking Interconnecting 5G-RAN with Compute Resources
- Optical Networks in Support of 5G and B5G
- Service Continuity in 5G Systems
  - Through Dynamic Resource Management
- Demonstration Activites
- Conclusions

5G and Beyond Vision and Services

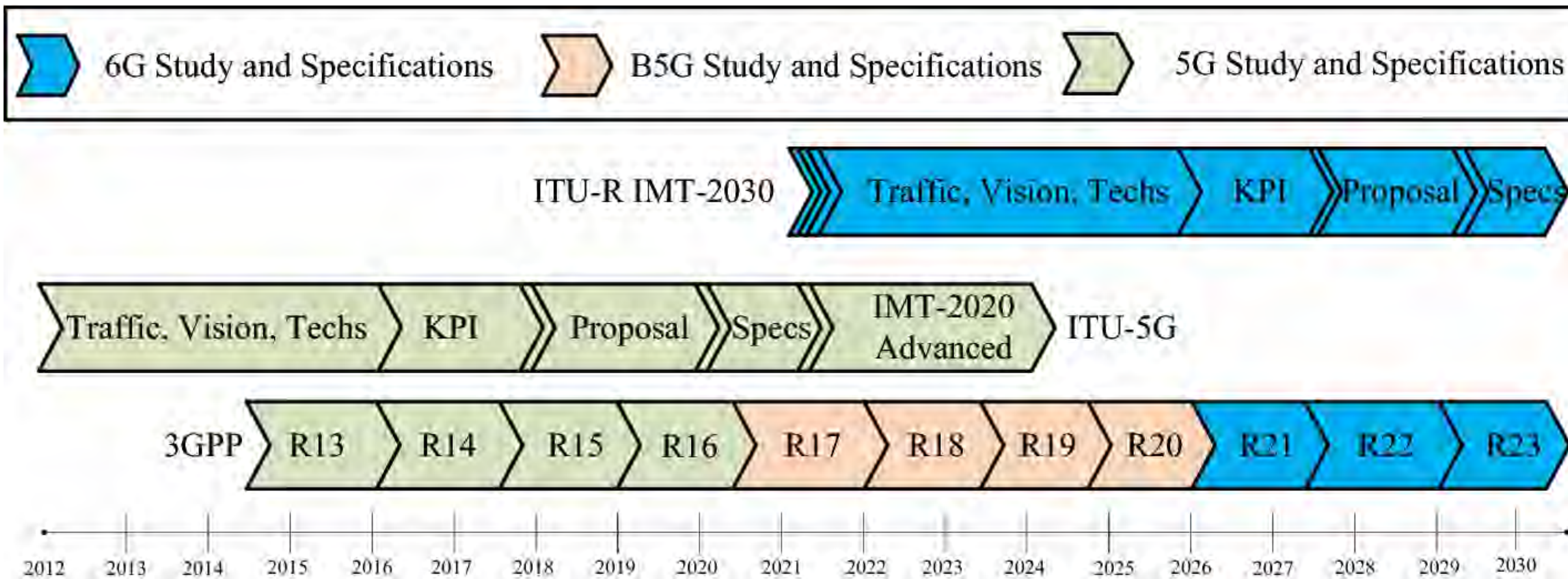
Motivation - 5G and Beyond Vision

- New business opportunities for a large variety of industries – ICT & Verticals
- 5G Networks to be future proof: architecturally designed to evolve and not to be replaced
  - Beyond 5G incremental advancements
- Operational and end-user services
  - Ultra - Reliable Low Latency Communications (URLLC)
  - Enhanced Mobile Broadband (eMBB)
  - Massive Machine to Machine Type Communications (mMTC)

5G and Beyond – Technical Focus

- Technology Heterogeneity
  - Integration of different ***Network Technologies*** (wireless terrestrial and satellite, packet and optical)
  - Integration of ***Communication*** and ***Compute/Storage*** technologies
- Softwarisation and programmability
  - Paradigm shift from ***Network Entities*** to ***Network Functions***
  - Define interfaces and protocols to allow network functions to be configured in software decoupling control and user plane
- Slicing and virtualisation
  - Efficient ***resource sharing*** *and* ***multi-tenancy***
- Artificial intelligence/machine learning
  - Adoption of ML and AI techniques to optimally manage infrastructure resources in support of service requirements
- Air interface
  - Unlicensed bands e.g. mmWave and Terahertz frequency ranges changing the emphasis from spectrally optimized solutions to improved coverage solutions
  - Massive MIMO solutions
  - Advanced beamforming, intelligent reflective surfaces

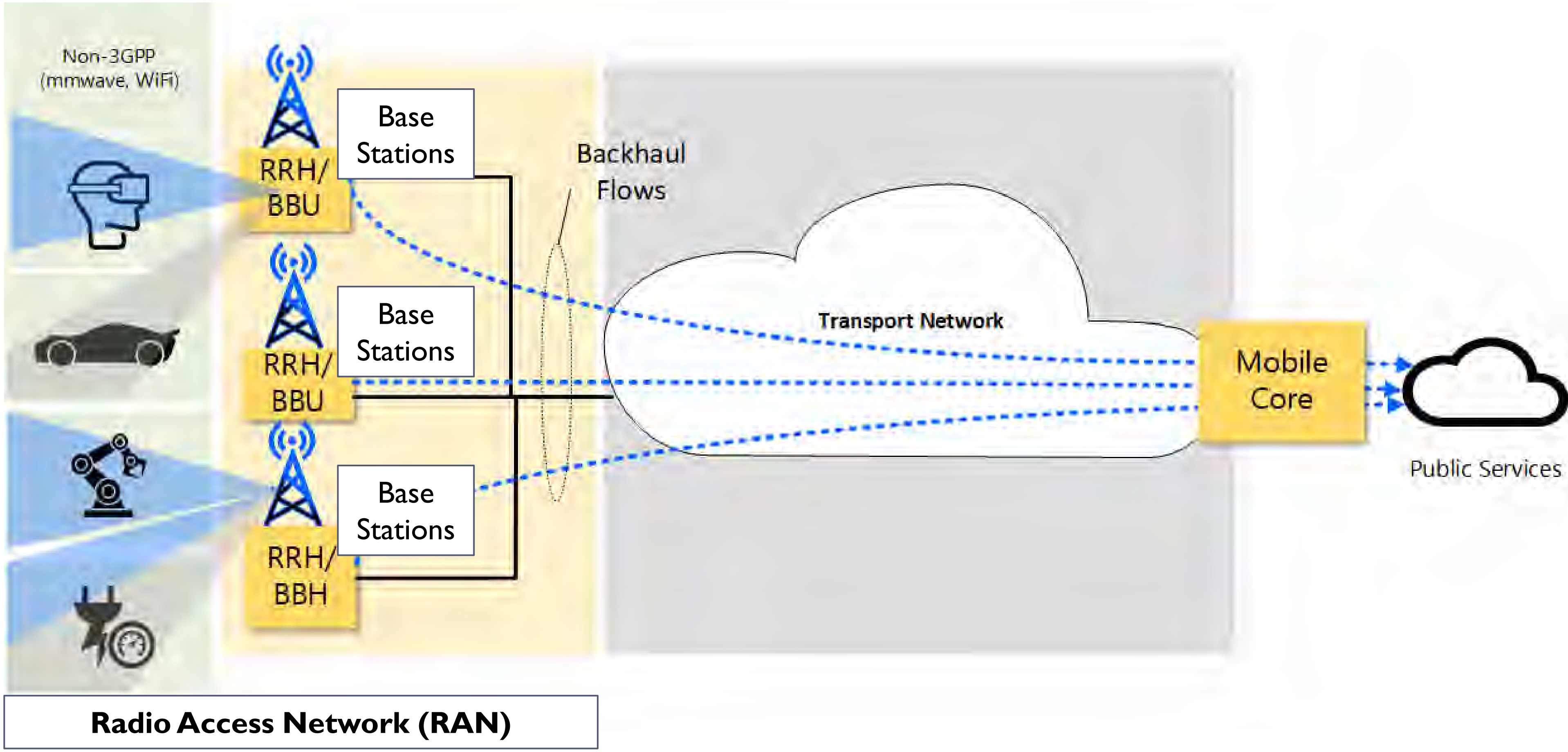
5G, Beyond 5G and 6G Specification Status



1. Mourad A, Yang R, Lehne PH, De La Oliva A (2020) A baseline roadmap for advanced wireless research beyond 5G. Electronics 9(2):351
2. Gozalvez J (2015) Tentative 3GPP timeline for 5G [mobile radio]. IEEE Vehicular Technol Magazine 10(3):12–18

5G Architectural Considerations

Mobile Network Functional Architecture



Migration to 5G

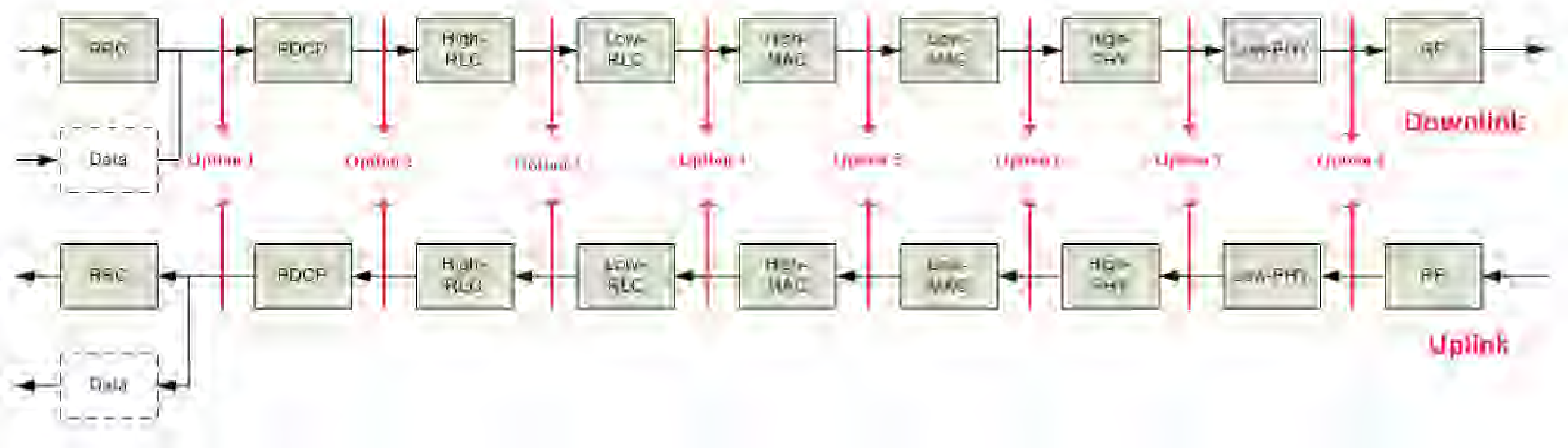
- New business opportunities for a large variety of industries – ICT & Verticals
- 5G and Beyond Networks: Main Technological Advancements
  - Transformation of the Core Network and separation of user and control plane functions

1. Functional entities
2. Single Core
3. Dedicated protocols

1. Services
2. Virtual Core
3. Internal Communication: APIs
4. Harmonized protocols
5. Function/service exposure
6. CP / UP Separation

- Common Core Network
  - Common network for 3GPPP and Non-3GPP elements
- Service Based Architecture (SBA)
  – Architecture elements are **network functions** that offer their services via interfaces of a common framework
  – This architecture model is chosen to enable deployments to take advantage of the latest virtualization and software technologies

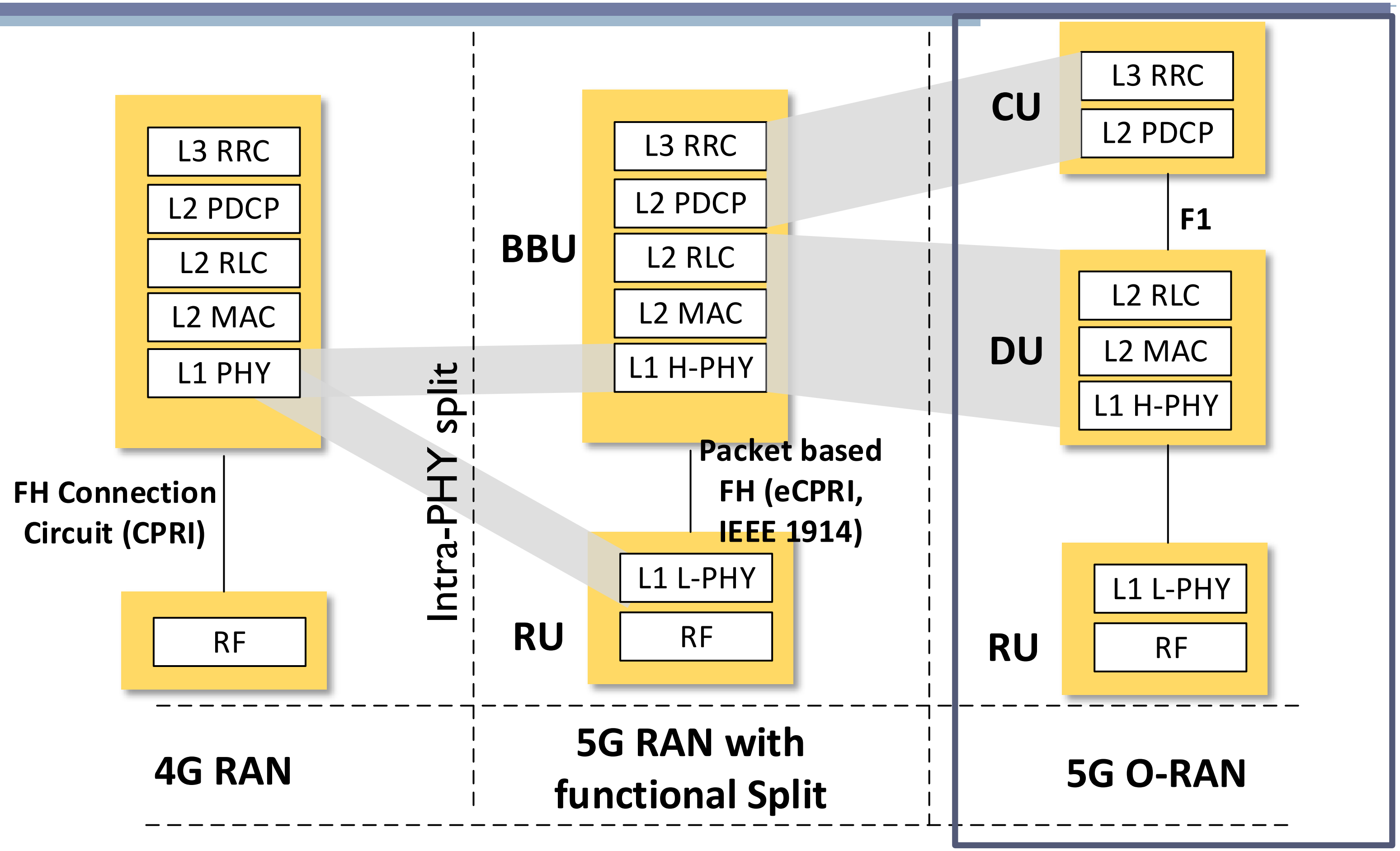
BBU Functional Splits



- Flexible split processing to relax the stringent requirements of FH services for:
  - transport capacity
  - delay
  - synchronisation

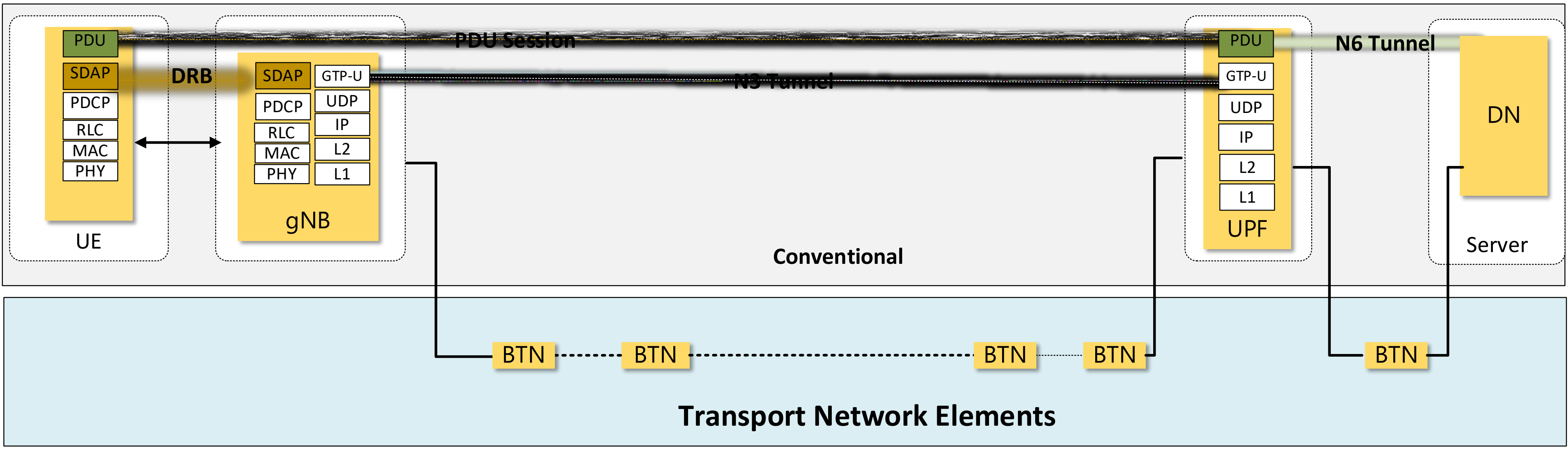
3GPP TR 38.801 Radio Access Architecture and Interfaces Release 14

RAN Architectural Evolution: 4G to 5G to 5G Dissagregated RAN



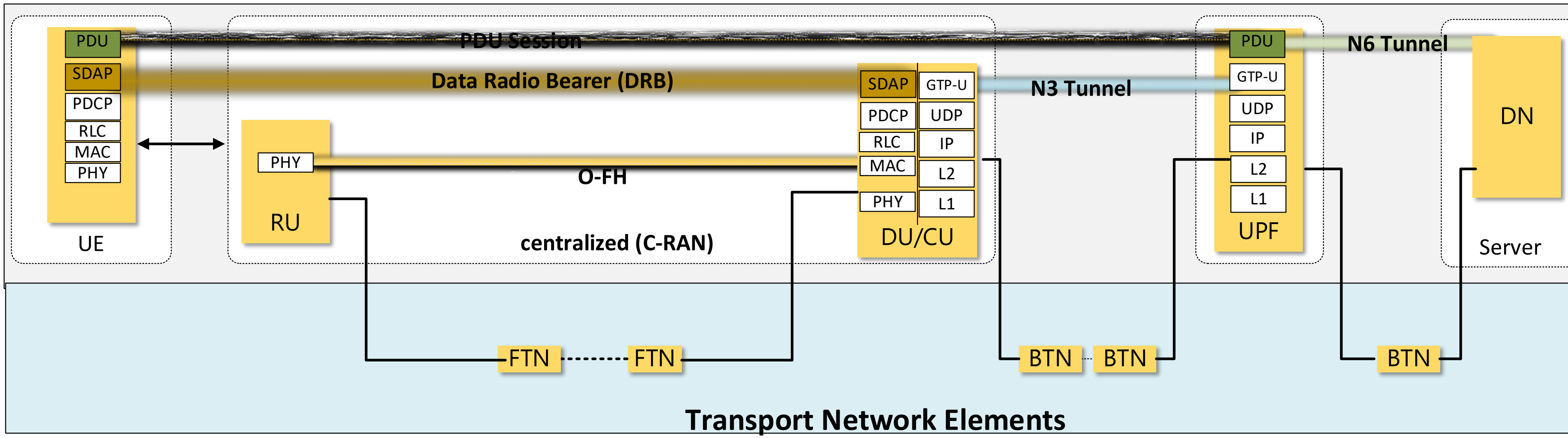
RRC: Radio Resource Control
PDCP: Packet Data Convergence Protocol
RLC: Radio Link Control

Monolithic deployment



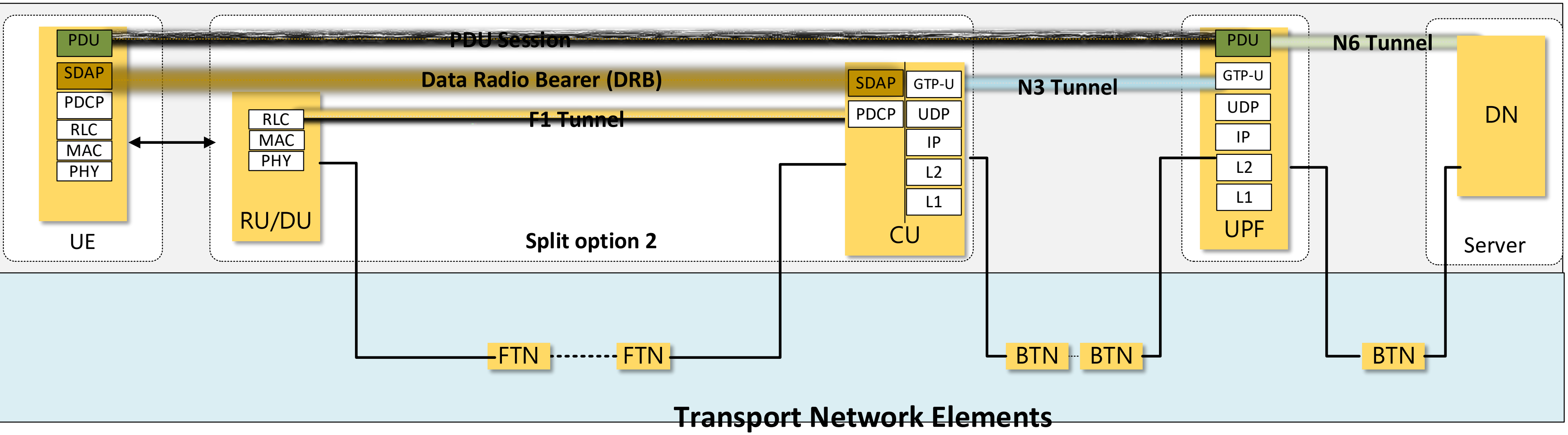
- CU, DU, RU and their corresponding RAN functions and protocols are co-located within the same site.
- This deployment option resembles the current LTE systems deployment and offers backward compatibility with the LTE Enhanced Packet Core (EPC).

FH Functional Split: Centralised C-RAN architecture



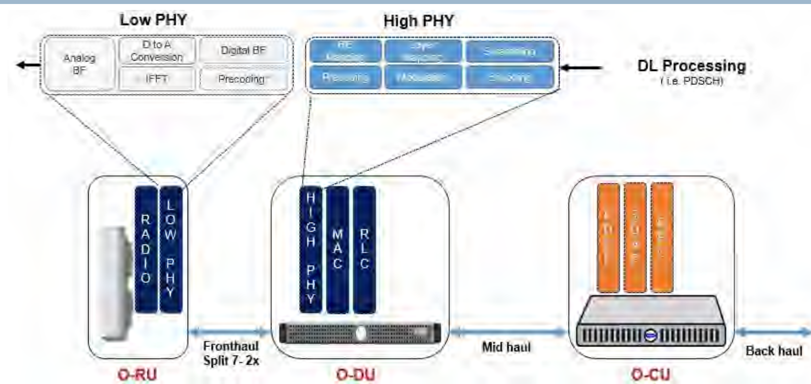
- The DU and CU are collocated and RU is hosted at a different location

FH Functional Split: Split Option 2

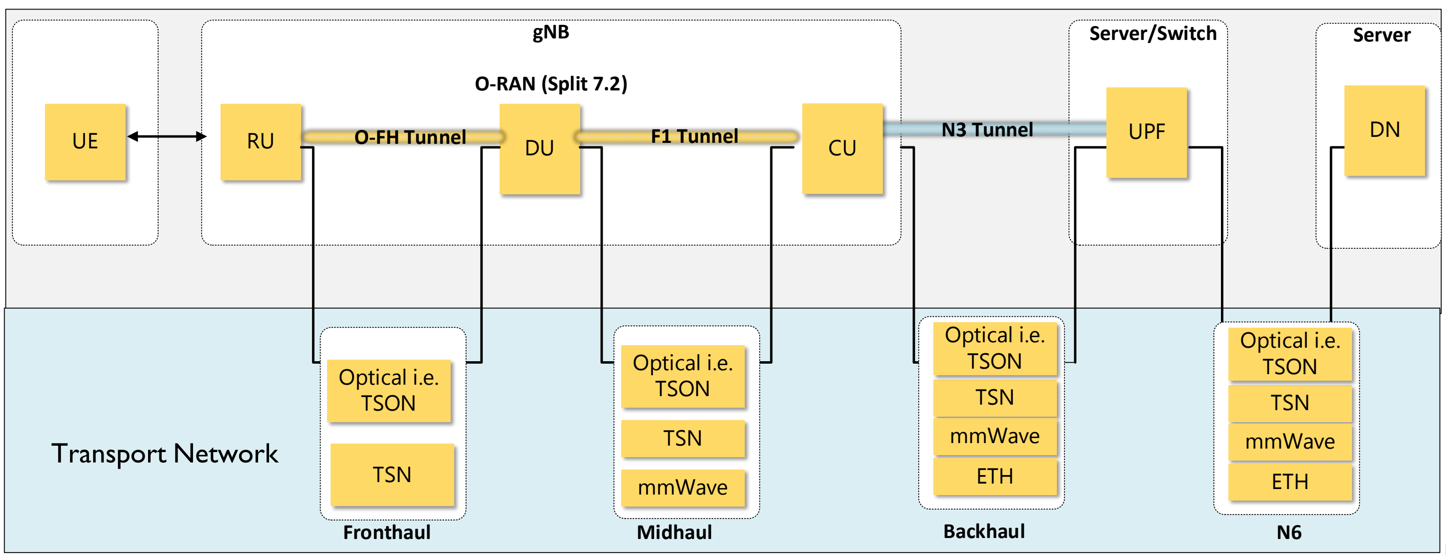


- The RU and DU are collocated and CU is hosted at a different location

Dissaggregeted RAN
Fronthaul, Midhaul and Backhaul



Open - Radio Access Network (O-RAN) Alliance
Dissaggregated Radio Access Network Architecture
O-RAN units are controlled by the Radio Intelligent Controller (RIC) adopting AI techniques



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UPF - User Plane Function

- Provides connectivity with the external Data Network
- Acts as a stable anchor point for the devices toward external networks
- Hiding mobility related aspects

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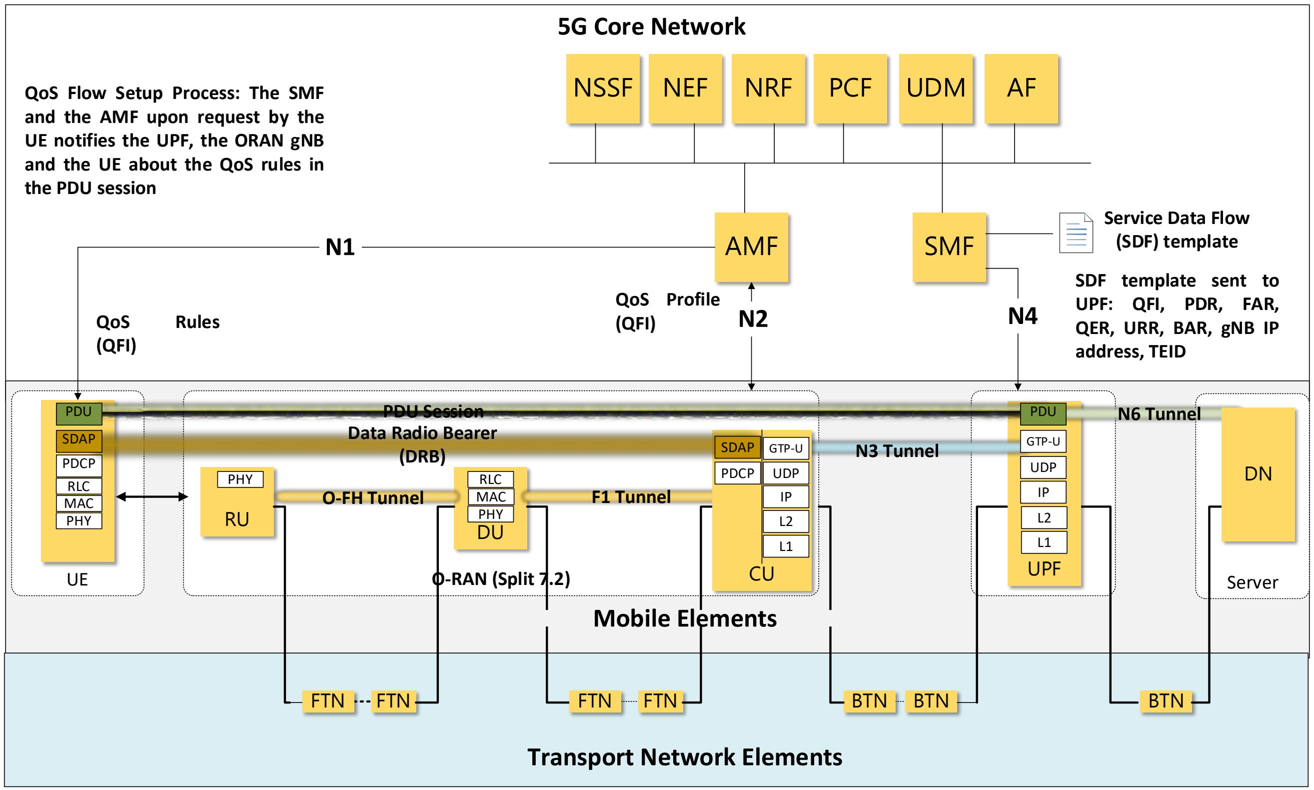
5G SBA Reference Architecture



The generic 5G architecture as defined by ETSI, 3GPP, IEEE and O-RAN

5G-Architecture: SBA comprising "**Network function** service" + "Service-based **interface**"

AMF: Access and Mobility Management
- supports encrypted signalling, registration, authentication, and moving between cells

SMF: Session Management Function
- Manages establishment, modification and release of individual sessions

UPF: User Plane Function
- Processes and forwards user data using the N3 interface and its functionality is controlled from the SMF.
- It connects with external IP networks and acts as a stable anchor point for the devices toward external networks, hiding mobility related aspects

NSSF: Network Slice Selection Function
- Aware of all network slices and AMF(s) dedicated to each slice
- Selects the set of slices and AMF(s) that should serve the UE.

NWDAF: Network Data Analytics Function

Key challenge: Multiple Service Based Interfaces with different network requirements

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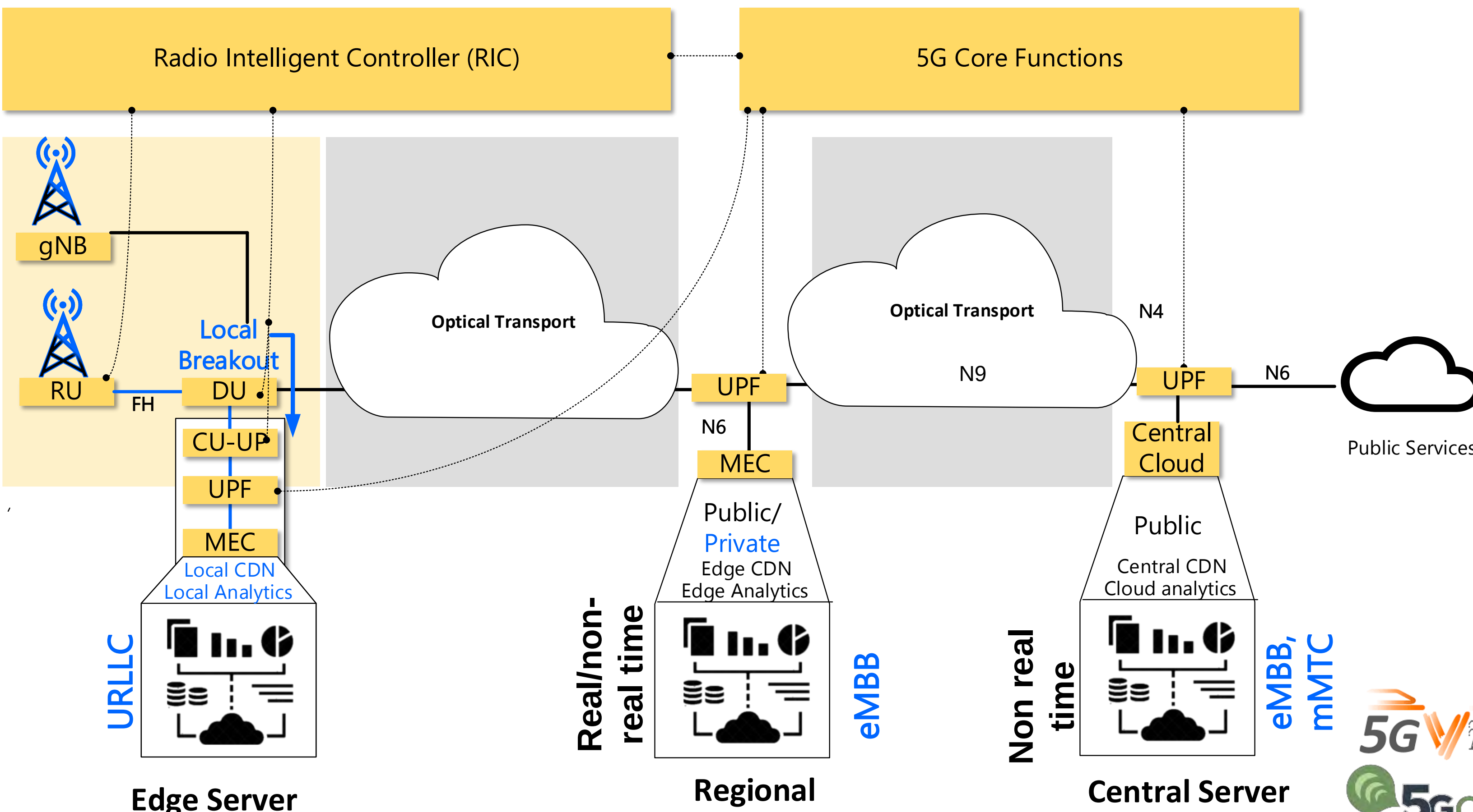
5G Architecture Compute Perspective

- Flexible placement of network functions to address different services



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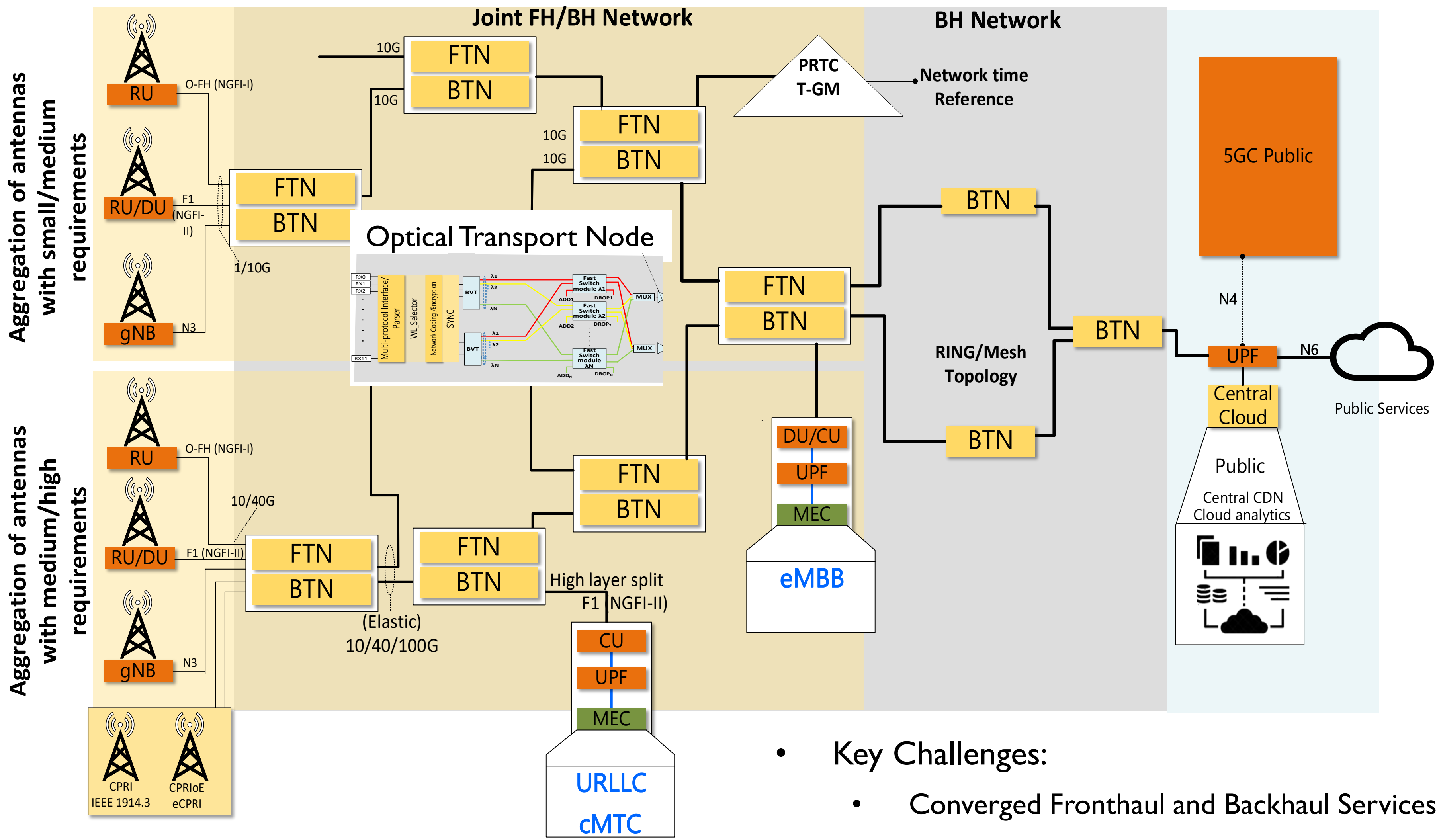
Optical Networks in Support of 5G Systems and beyond

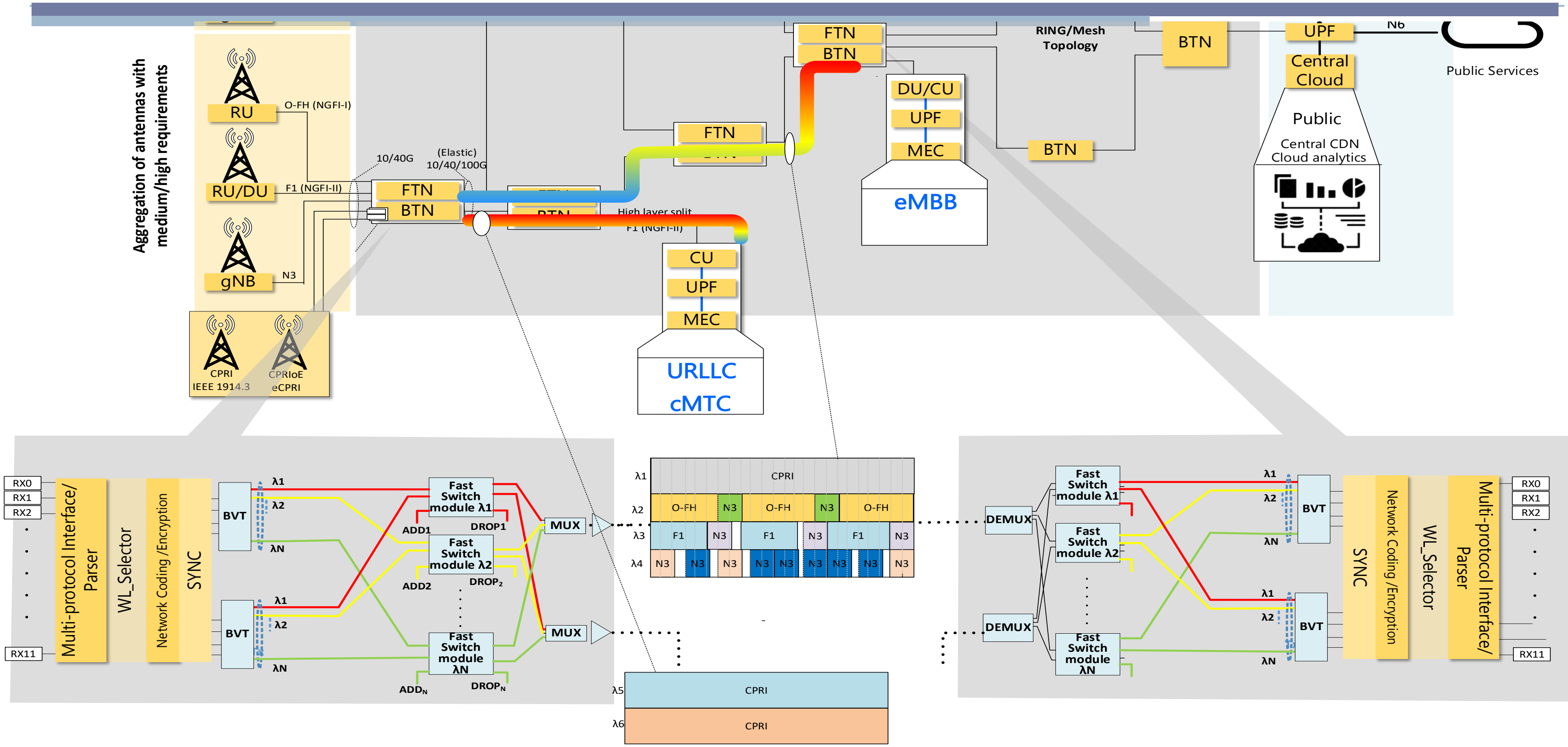
M. Anastasopoulos, A. Pelekanou, A. Manolopoulos, A. Tzanakaki and D. Simeonidou, "Optical Networks in Support of Open-RAN in 5G Systems and beyond", ECOC2021

Optical 5G Transport Network



- Key Challenges:
  - Converged Fronthaul and Backhaul Services
  - Converged Network and Compute Services
  - Disaggregation of Resources

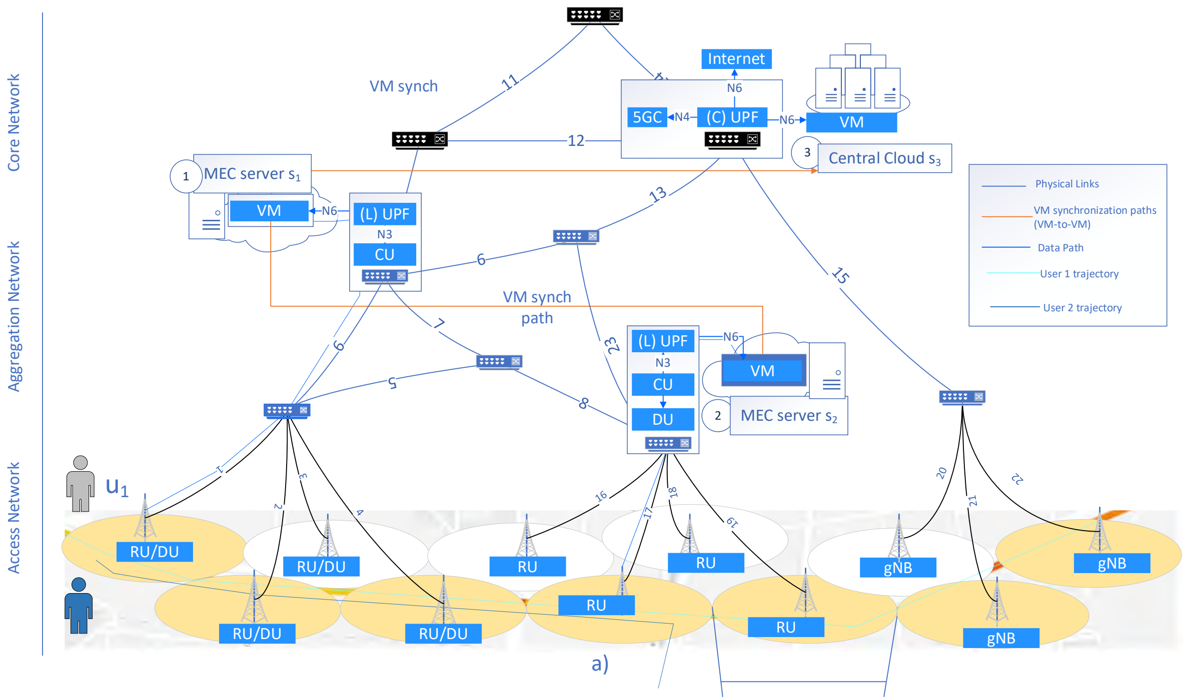
Optical Transport Node



- Proposed Solution – Time Share Optical Network:
  - Variable length optical frames supporting sub-wavelength switching granularity
  - Optical network elasticity in the frequency domain
  - Addresses efficiently the greatly varying bandwidth requirements of 5G services

Modeling Framework

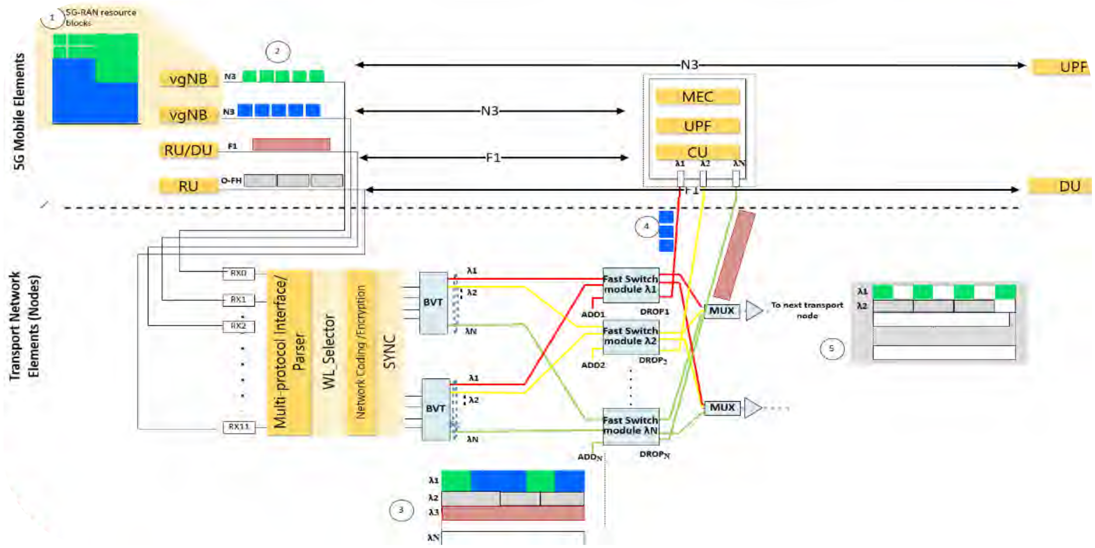
- We consider a 5G network interconnecting a set of RU-DU, CU, UPF, DN elements creating end-to-end service flows



- End-to-end connections can be successfully established if optical network resources (i.e., wavelengths, timeslots) are available across the end-to-end path.
  - This problem can be formulated as an ILP model

Modeling Framework

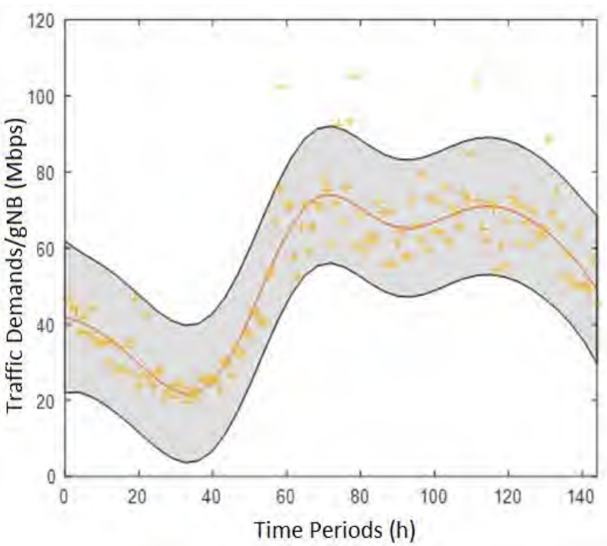
- **Objective**:
  - Maximize a utility function considering both the network and compute elements
- Subject to
  - End-to-end connectivity constraints: service chain RU-DU-CU-UPF-DN
  - Demand constraints: Allocation wavelengths and timeslots to the appropriate interface at each time period ~ ***Joint routing, wavelength and timeslot allocation problem***



- Given that this problem is computationally intensive, we split it into simpler sub-problems.

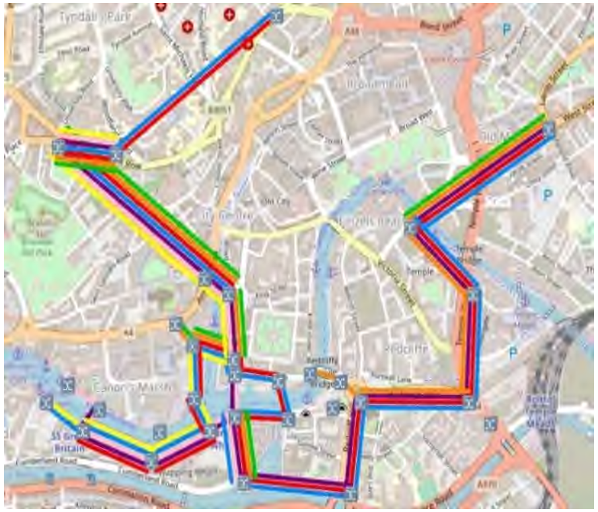
Modeling Framework

- ***First stage problem ~ Connectivity***
  - We estimate the total number of demands to be served within a specific time frame
  - We solve the RWA wavelength per connection to identify the optimal network path consisting of links and switches along which the flows are transferred from the gNB to the destination (i.e. UPF, MEC)



Estimation of Traffic Demands applying the GPR method,

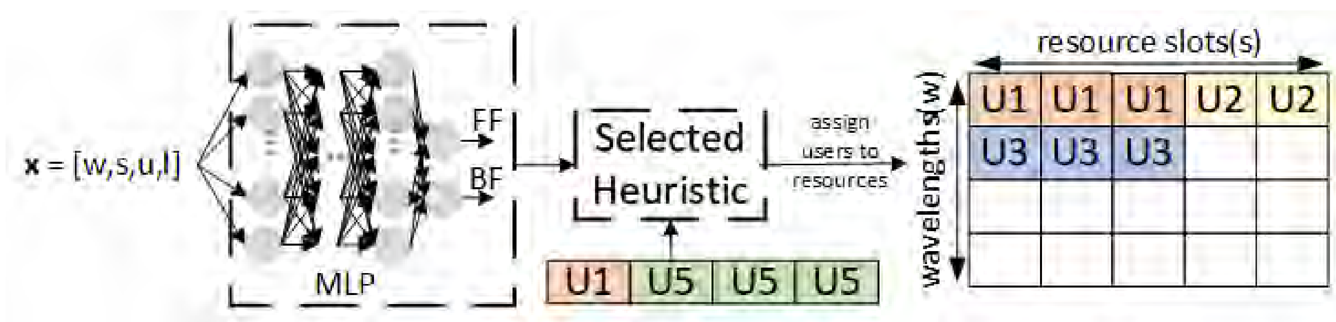
Bristol topology



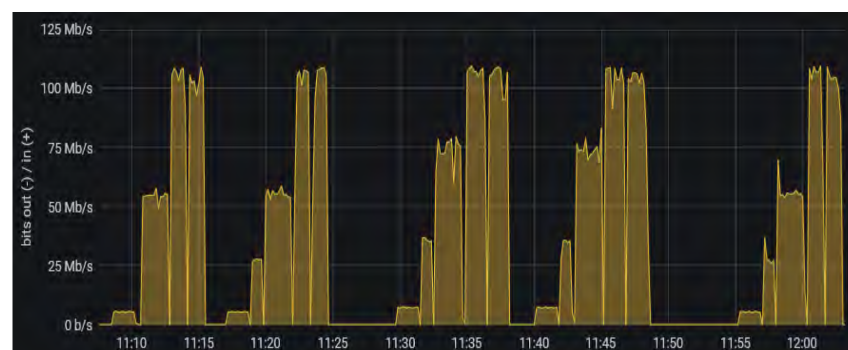
Optimal paths/wavelengths used for the interconnection of the RUs with the DNs

Modeling Framework (2)

- ***Second stage problem:***
  - Once the end-to-end connections have been established, the controller solves the optimal scheduling problem at timeslot level adopting ML.
  - Scheduler based on Multilayer Perceptron (MLP)-neural networks (NN).
  - The MLP NN can identification of the optimal scheduling policy (i.e. first fit, best fit etc) under different traffic input statistics, topologies, etc

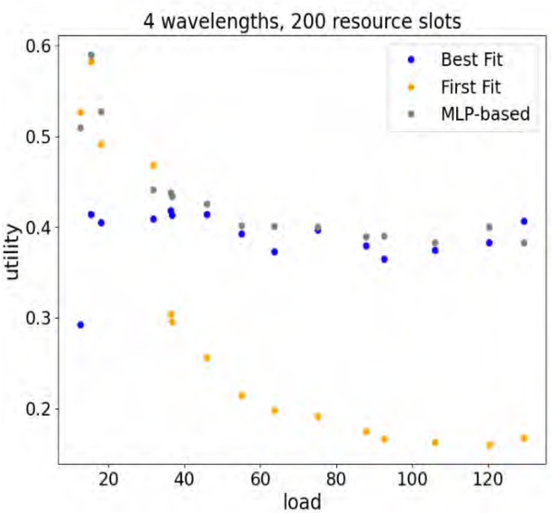


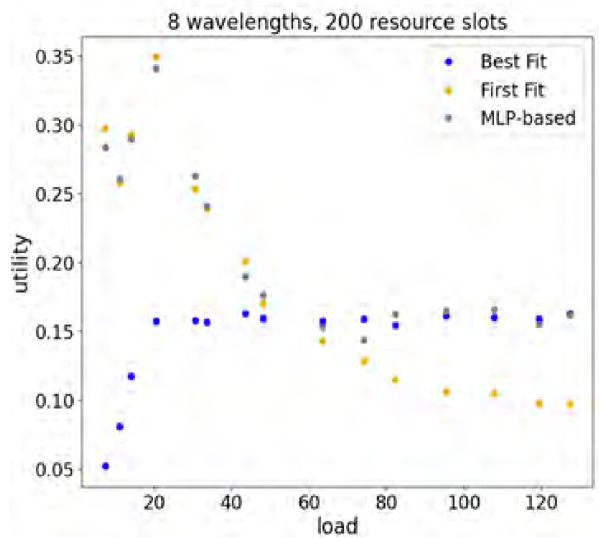
- Training dataset: The MLP NN has been trained using a network traffic generator emulating the characteristics of the different 5G interfaces
- 5G traffic characterization based on measurements collected from open-source 5G platforms installed in the cloud (Free5GC and OAI)

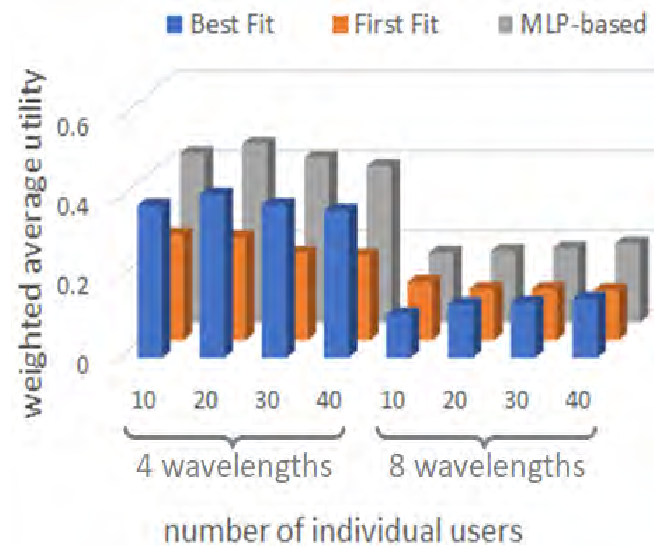


Network traffic per UE

Numerical Results







- The ML scheduler selects
  - Under low traffic conditions the a simple scheduler due to its low computational cost
  - Under High traffic conditions more sophisticated scheduling policies in order to minimize fragmentation

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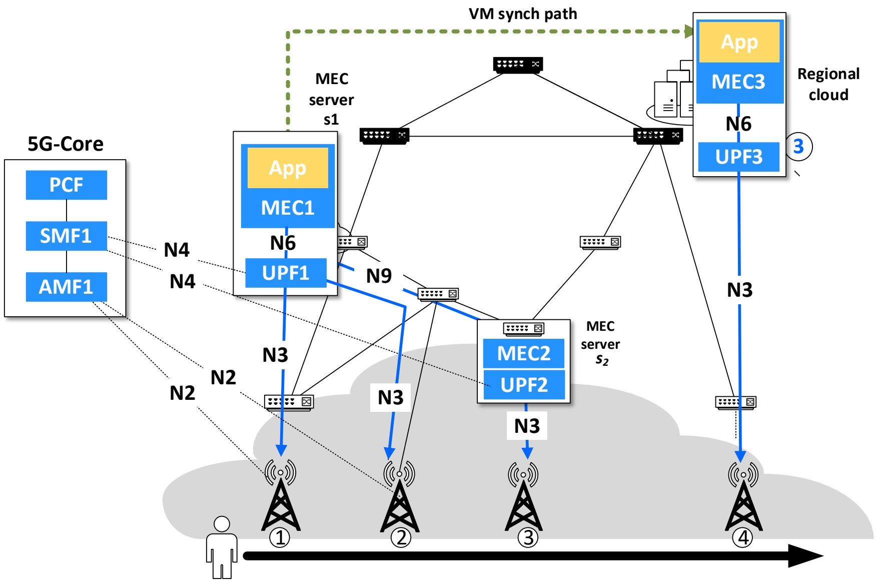
Service Continuity in 5G Systems through Dynamic Resource Management

Anna Tzanakaki, Markos Anastasopoulos, Alexandros Manolopoulos, "Mobility aware Dynamic Resource management in 5G Systems and Beyond", ONDM 2021, invited

User Mobilty Scenario and Solution

- UEs are interconnected to the MEC node through the 5G-system
  - Mobile UEs should be always connected with MEC facilities hosting their applications using suitable interfaces
  - As the UE moves the distance between the UE and the MEC changes introducing variability in the end-to-end packet latency
  - Service continuity is ensured through two different mechanisms operating at different time scales:
    - A handover process operating at a short time-scale (milli-second) ensuring UE connectivity with the 5G-RAN
    - A service migration process at longer time-scales (seconds) ensuring seamless access of the UE to the application content (MEC platform)
- We considered joint user handover and VM migration to ensure service continuity in 5G environments meeting service level requirements
  - Handover: seamless connection to the 5G-RAN i.e. appropriate UPF selection, insertion of I-UPF and anchoring
  - Selection of suitable MEC node to support the service: VM migration between MEC nodes in accordance with the follow me cloud paradigm

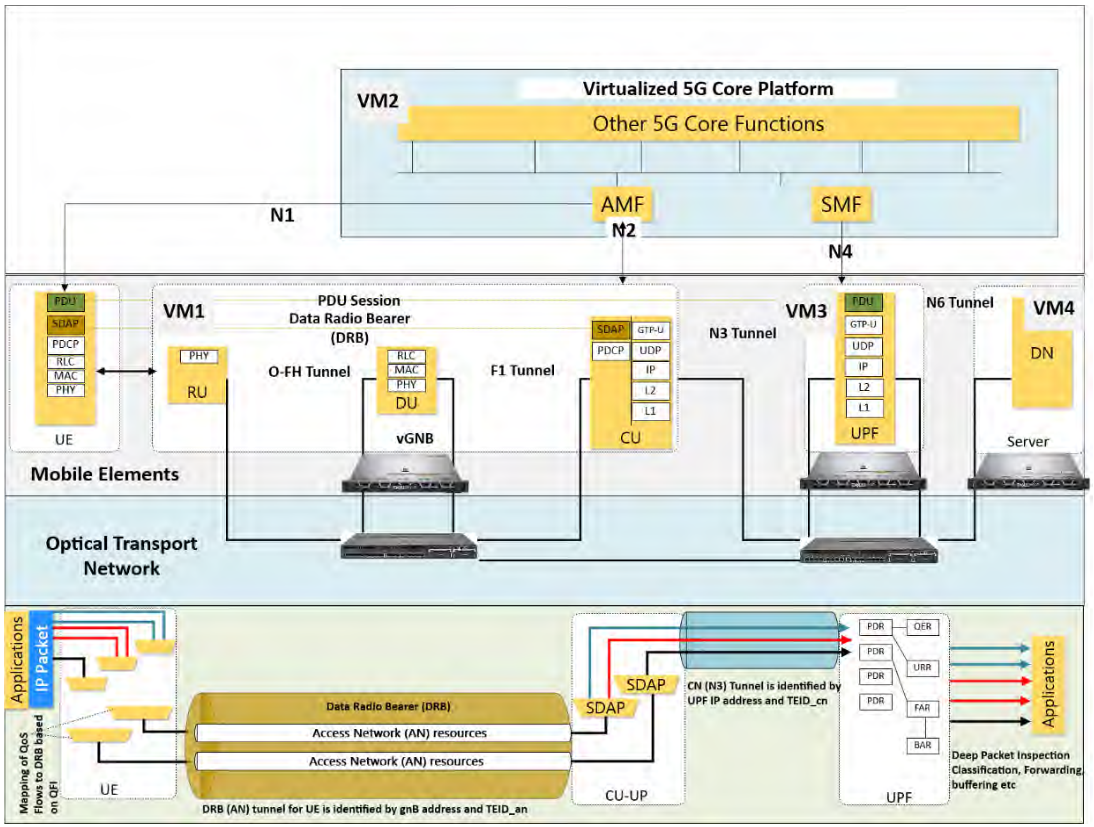


5G platform implimentation

- Two different 5G platforms have been deployed in a lab environment
  - OpenAirInterface - a standalone (SA) 5G platform
  - Free 5G-CORE a Standalone (SA) 5G platform
- Both platforms have been deployed in virtualized servers
- Detailed profiling of compute and network resources required to provide end-to-end network slices
  - uRLLC, eMBB and mMTC services

Private cloud platform used for lab testing of the 5G-COMPLETE system

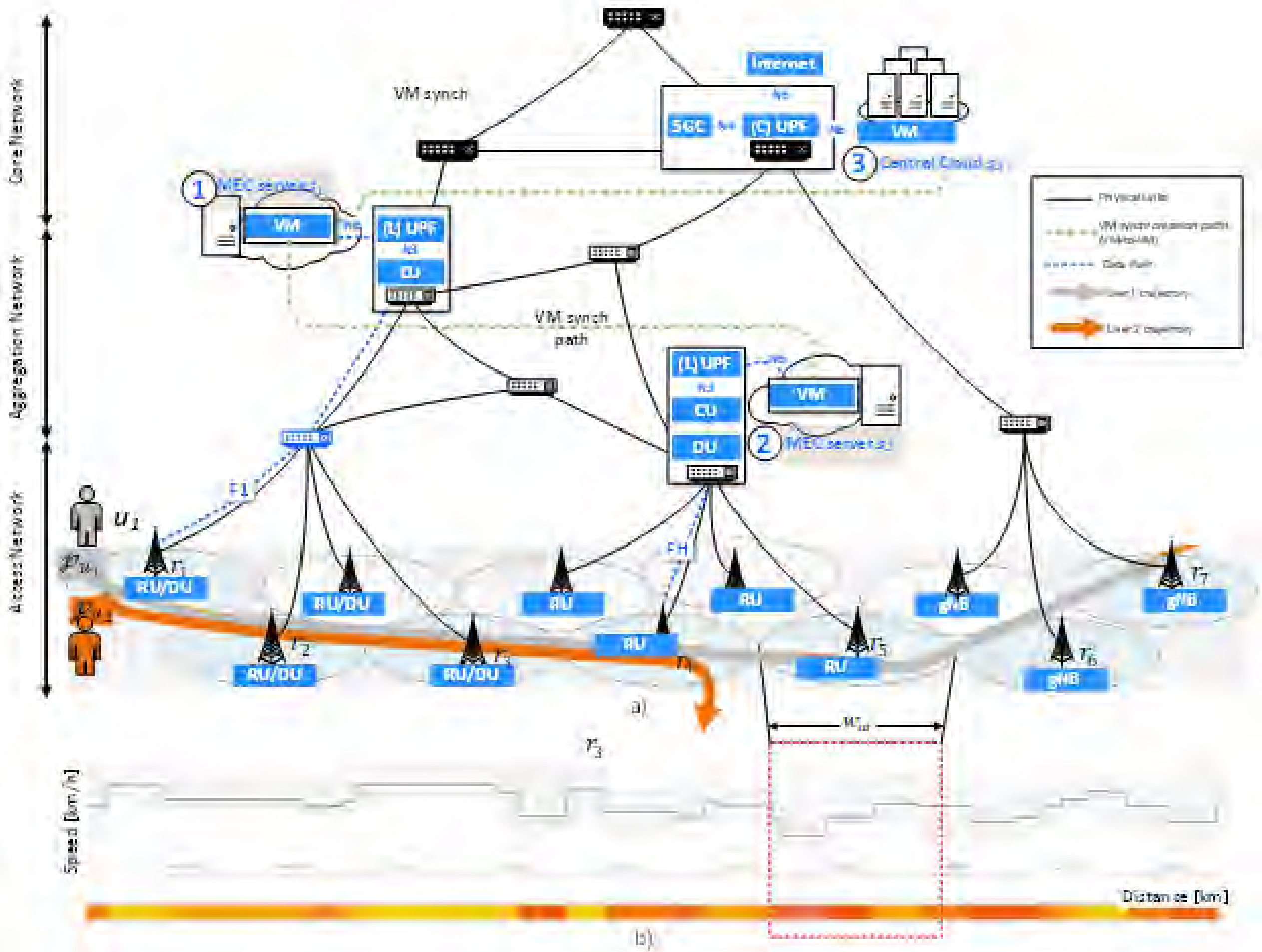
5G System Set-up



- Virtualized servers are hosting the two 5G-platforms comprising 5G-RAN and 5G-CORE components supported by VMs hosted at physically separated servers
- A VM hosting the end-user services has been also deployed at a different server
- These are interconnected with electronic/optical switches

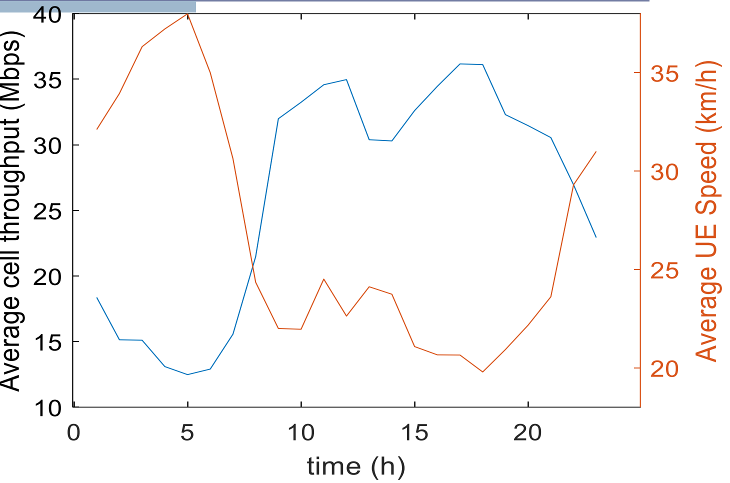
Evaluation Studies (I)

- Network Scenario
  - Hierarchical Optical Transport Network interconnecting virtualised 5G-RAN and 5G-CORE elements
  - Mobile UEs request access to compute resources hosting their applications (MEC and cloud)
    - End-to-end connections are established between UEs and compute resources over the 5G network
  - 5G network topology assumed based on a real urban cellular deployment

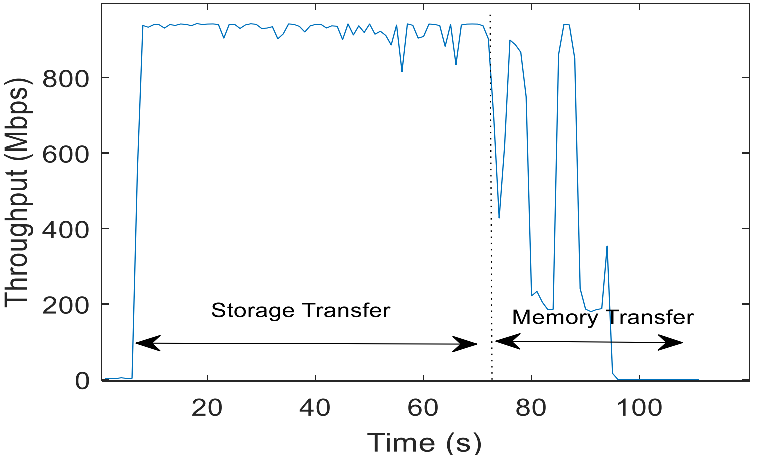


Evaluation Studies (II)

- Real network traffic statistics and user mobility statistics
  - Corelation of UE mobility speed with mobile network traffic
  - These are used to estimate the user residence time per gNB and the overall traffic load per cell
  - This allows estimation of input mobile traffic statistics for every cell
- Optimisation based on a multi-stage ILP model
  - The ILP decides the UPF where the PDU session will be terminated and the MEC node where the user application will be hosted
  - When a new optimal MEC node is identified by the ILP a VM migration process is triggered
  - The VM migration process introduces some overheads which are also incorporated in the analysis



Interrelation between the average mobile traffic per gNB and the average speed per UE

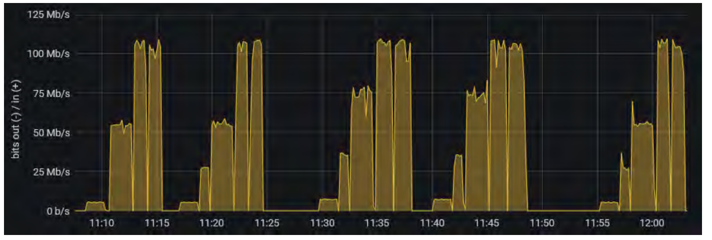


Network traffic generated during the migration from a source to a target MEC server

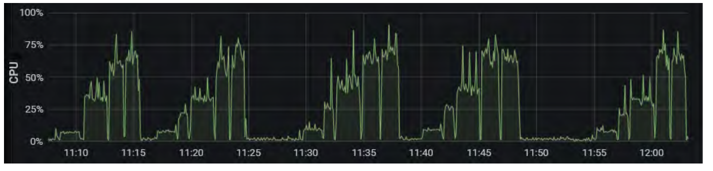
Cost Function

1. Evaluate the system under realistic network traffic conditions and cost function
2. The cost function considers the weighted average of the network and compute elements utilization
3. Realistic cost functions for network and compute resources under mobility
    - using measurements collected from the experimental platform
4. A penalty is applied when service latency increases

5G-Platform Set-up and Output



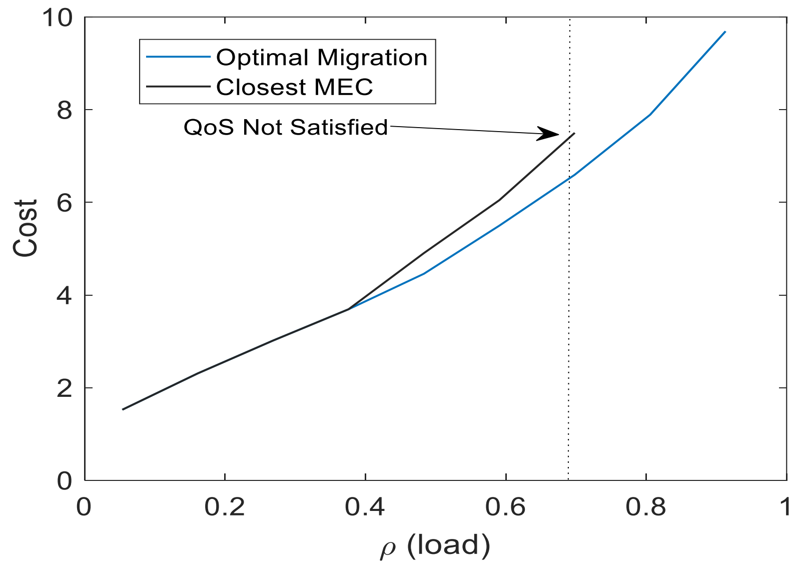
Network traffic per UE



UPF CPU utilization

- UEs establish end-to-end connections through the UPF to the DN requesting a specific file transfer
- All measurements have been collected through Prometheus
- These measurements are used as input to a set of optimization studies targeting the network planning and service provisioning problem over converged 5G infrastructures
- The developed algorithms were able to handle both slow and fast changing traffic patterns establishing connectivity between 5G-RAN, CORE and MEC elements
- This has been achieved through the identification of optimal network resources required at the optical transport to support the relevant protocols and interfaces such as the O-FH, the F1, N3, N6 and N9 interfaces

Joint UPF and MEC placement - Results



- Under high loading, for the closest MEC VM migration policy, MEC resources are not sufficient to handle both operational and user services (i.e. 5G CORE. 5G RAN and application server).
- In this case, a migration (if allowed) will overload the system resulting in degradation of the system performance.
- On the other hand, the model that considers all components of the 5G network, will optimally place VMs to appropriate servers ensuring service continuity for a wider range of input traffic loads.

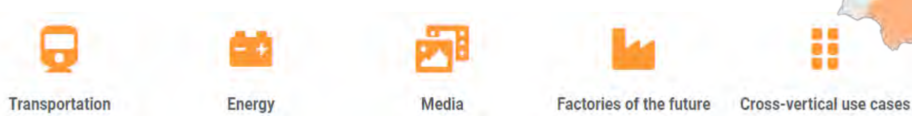
Demonstration activities

5G-VICTORI in a Nutshell

- **ICT-19 Project**

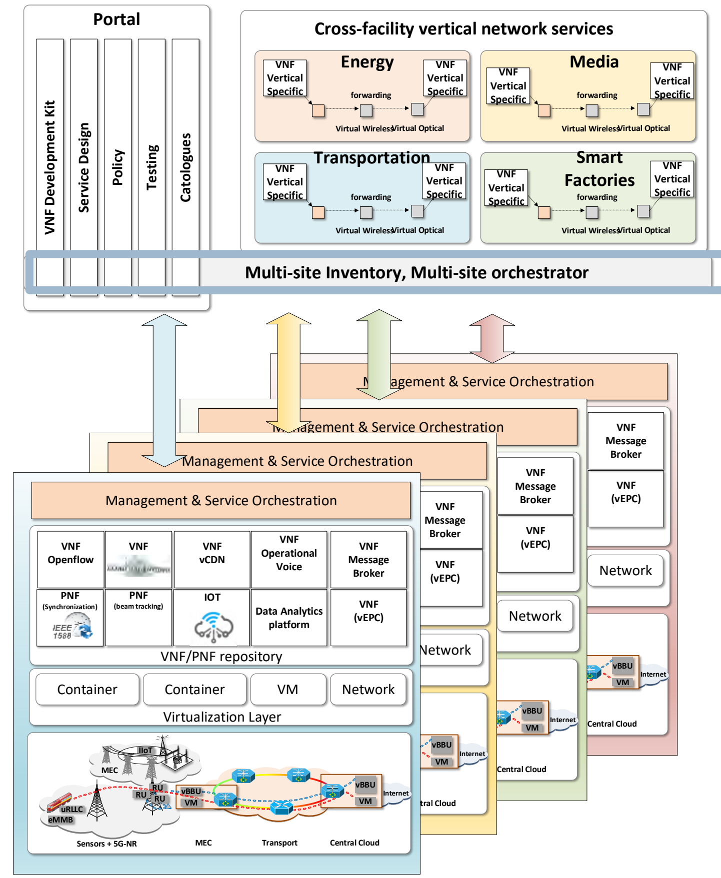
  "VertIcal demos over Common large scale field Trials fOr rail, eneRgy and media Industries"

- **Duration**: 3 years
- **Budget**: approx. 13.5 M€
- **Consortium**: 26 partners / 8 coun



5G-VICTORI Key Objectives

- **Transform** current **closed**, **purposely developed and dedicated infrastructures** into **open environments** where **resources and functions are exposed** to the telecom and the vertical industries through **common repositories**
- Design and prototype **an open 5G infrastructure** capable of instantiating and co-hosting various vertical sectors – adoption of slicing & virtualization
- Demonstration of the large variety of 5G-VICTORI vertical and cross-vertical use cases [1]
- Extension of ICT-17 Infrastructures & 5GUK towards the Integration of **commercially relevant**, **operational** environments [2] [3]
  - 5G-VINNI, 5GENESIS, 5G-EVE and 5GUK - Bristol



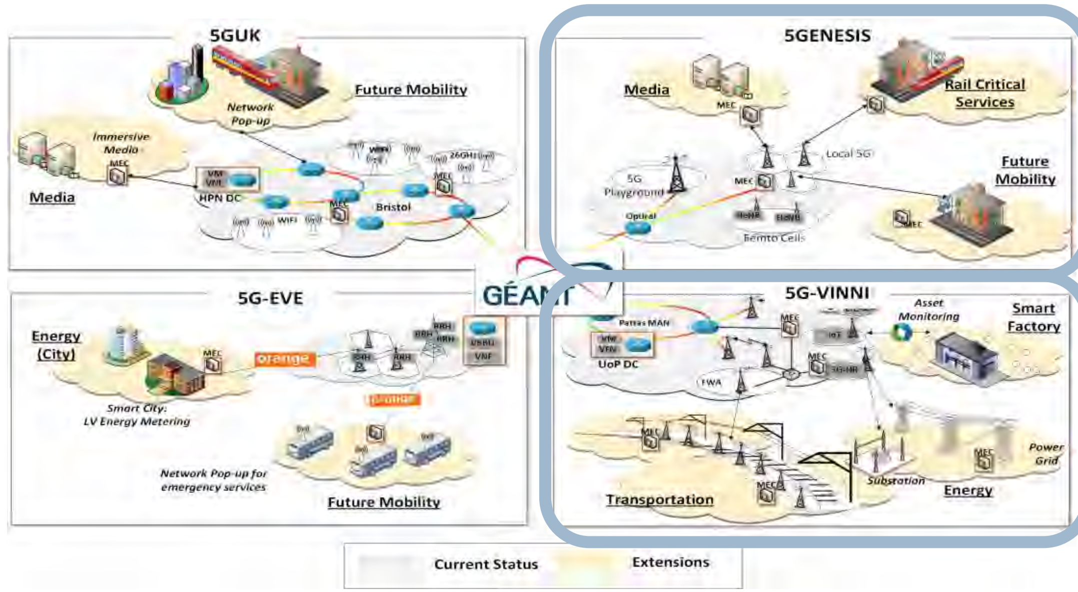
[1] 5G-VICTORI deliverable D2.1, “5G VICTORI Use case and requirements definition and reference
architecture for vertical services”, March 2020

[2] 5G-VICTORI deliverable D2.2, “Preliminary individual site facility planning”, July 2020

[3] 5G-VICTORI deliverable D2.3, “Final individual site facility planning”, May 2021

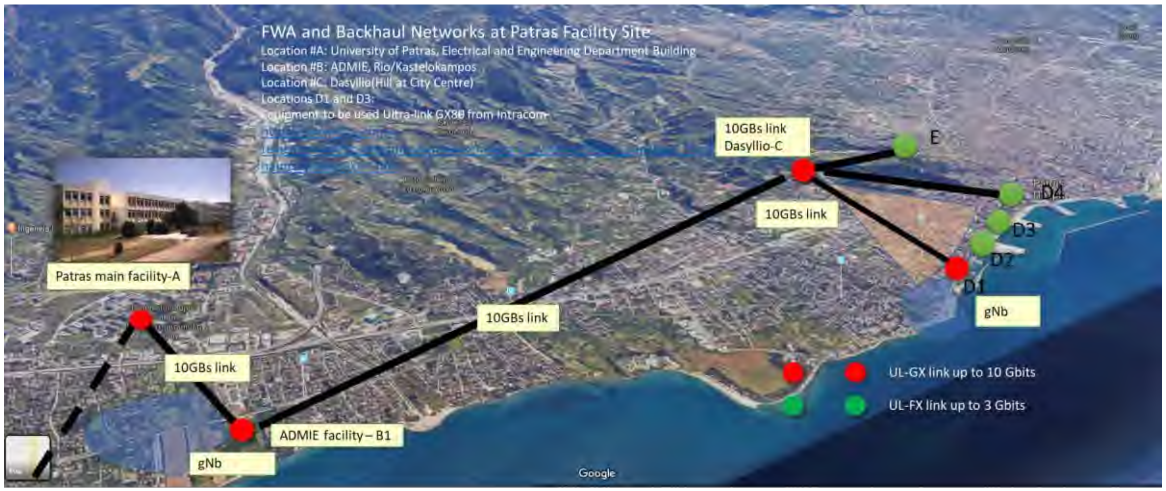
5G-VICTORI Use Cases and sites

- *"Enhanced Mobile broadband under high speed mobility", **Vertical: Transportation – Rail***
- *"Digital Mobility" **Cross-Vertical - Transportation and Media***
- *"Critical services for railway systems" **Vertical: Rail***
- *"Smart Energy Metering" **Cross-Vertical: Energy and Rail***
- *"Digitization of Power Plants" **Vertical: Smart Factory***
- *"CDN services in dense, static and mobile environments" **Cross-Vertical: Media and Transportation***



5G-VICTORI facility in Patras, Greece

(**Extension of 5G-VINNI**)



- A prototype network and deployment to facilitate train operations and services considering the FRMCS service definition
- Creation of two separate infrastructure slices that will concurrently
  1. provide "Business services" (eMBB slice) to train passengers using dedicated disaggregated femtocells deployed on-board, and
  2. support "Critical" (uRLLC slice) and "Performance" (eMBB + uRLLC slice) services over a heterogeneous Wireless deployment

5G Coverage at the Patras TRAINOSE facility

UL-GX link up to 10 Gb

Fiber link

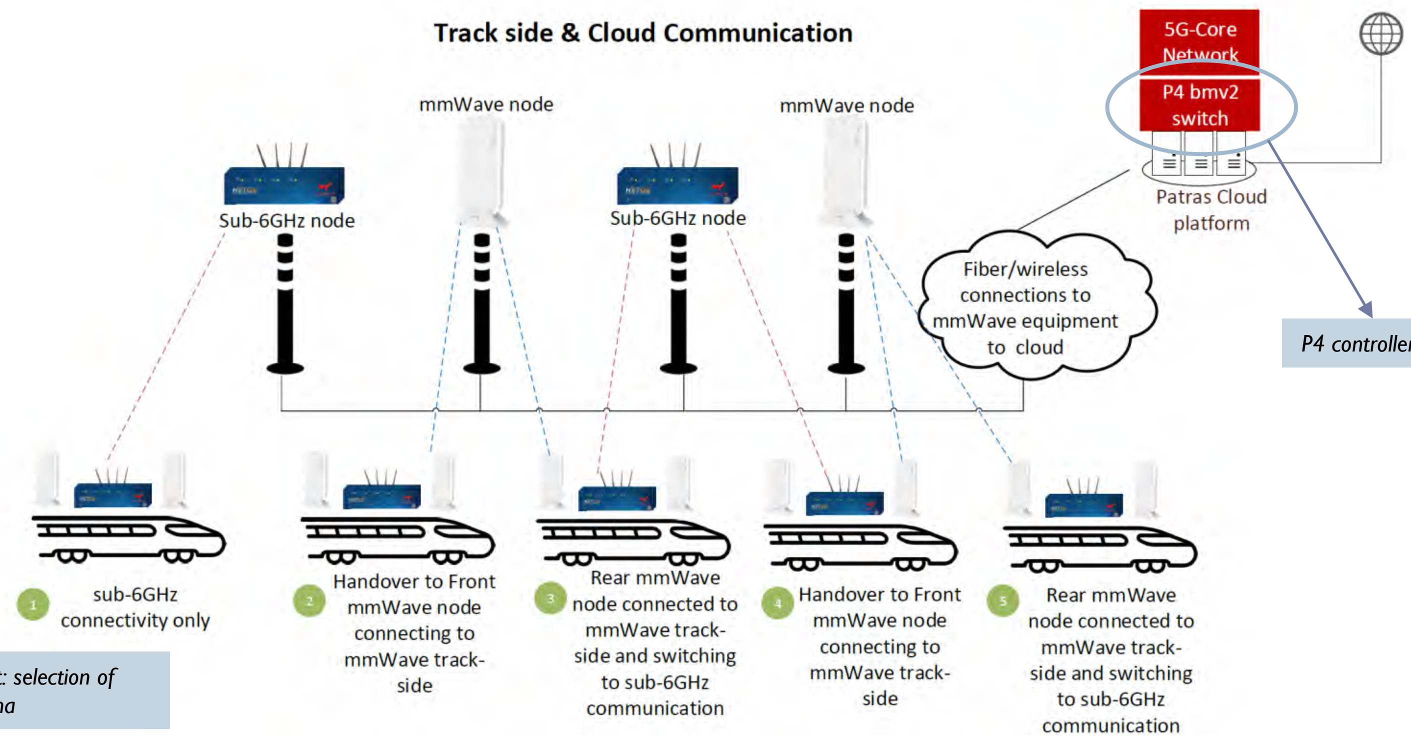
gNB base station

Sub-6GHz

60 GHz mmWave

05/2022

Multi-technology Transport Network - Mobility

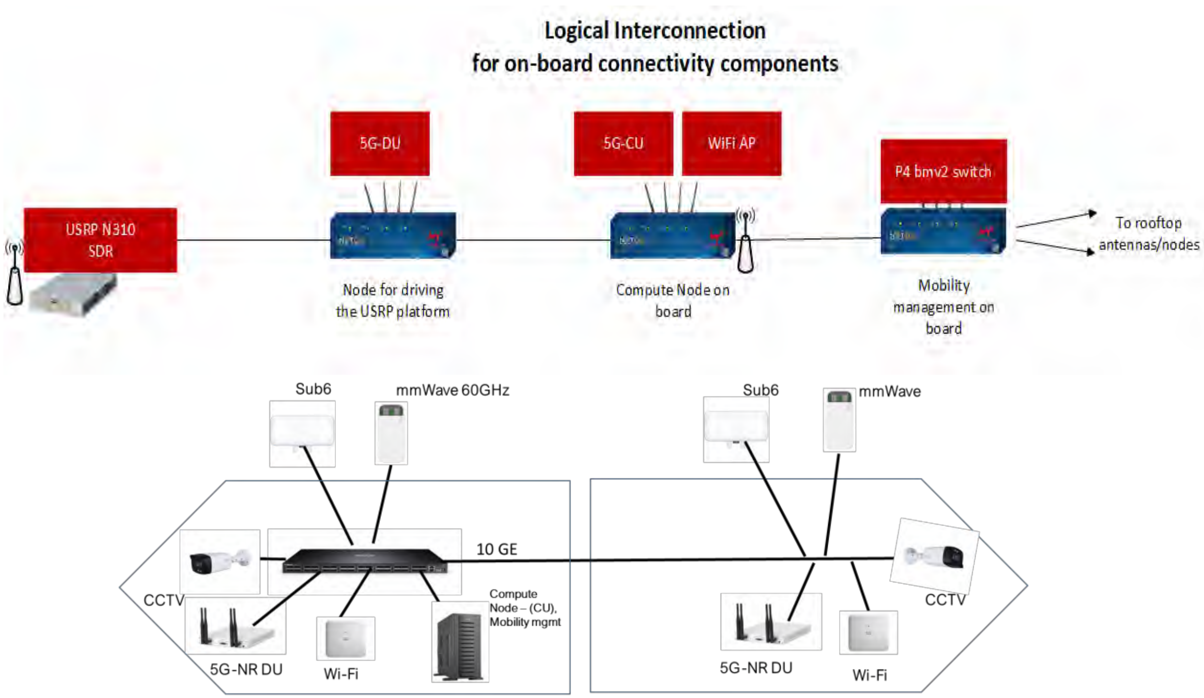


Handover Mngmt: selection of track-side unit

P4 controller manages the flows

Handover Mngmt: selection of technology/antenna

On board network deployment – Disaggregated 5G-RAN



Transportation use case @ Greek Cluster

5G VICTORI

Enhanced mobile broadband under high speed mobility in Rail environments

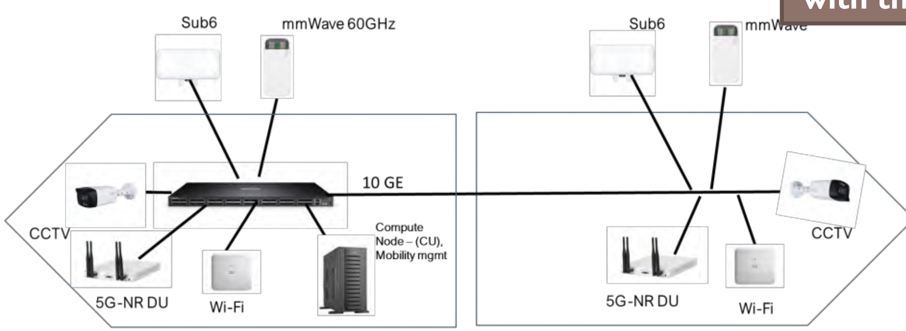
- Demonstrate a disaggregated multi-technology 5G cellular network addressing the railway environment specific requirements and challenges.
- Multi-technology transport network connectivity through a variety of technologies, including both mmWave and Sub-6 GHz technologies.
- Instantiate slices of the network in an E2E fashion to allow different types of services with strict KPI requirements such as latency and/or throughput.
- Provide high-speed, low latency network connectivity on-board (Cosmote TV, Critical operation services, CCTV camera on board)

Novelties

New network deployment to support the Use Case

eMBB functionality through disaggregated RAN on-board connectivity in a railway setup

Interconnection of on-board devices with the trackside and the trackside with the core network



Description	KPIs and Parameters
High Traffic Density	Total capacity offered to a single train / wagon
Mobility	Seamless service provision to wagons moving with high speeds
Latency	KPI: latency min. between UE and service end-points
Air Interface – Access/Transport Network Capacity	Antenna operation at high frequency bands delivering the required capacity
Air Interface Characteristics	Delivering the required capacity inside the train wagons, even at high speeds.

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Media Use Case @ Greek cluster

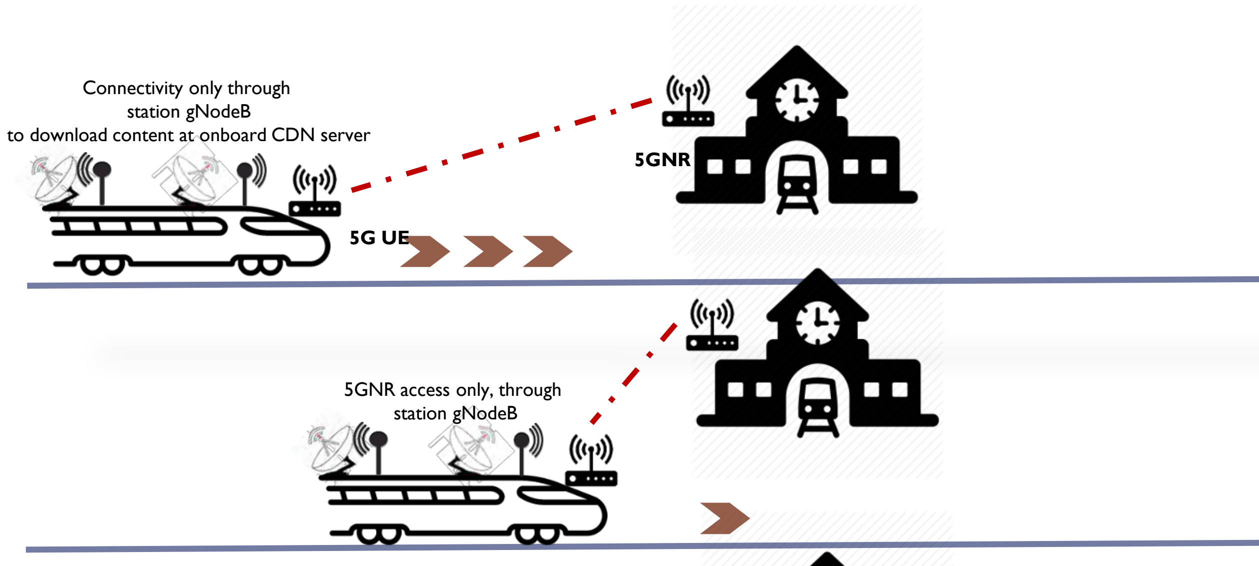
CDN services in dense, static and mobile environments

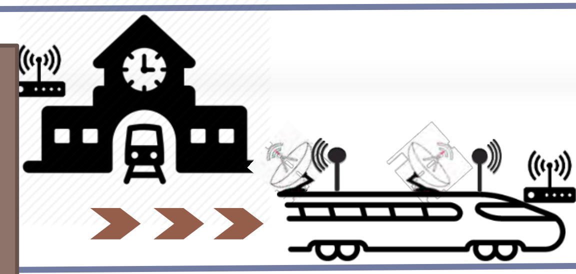
Demonstrate how eMBB services can be efficiently provisioned under static and high mobility scenarios over a dynamically re-configurable 5G ICT infrastructure to showcase:

i) onboard video streaming services (COSMOTE TV content) through ICOM fs|cdn™ Anywhere application

ii) service continuity for VoD & near-real time streaming services through opportunistic bulk transfer of large volumes of selected content.

- **CDN at Patras:** When approaching, the train connects to the station through 5G NR and downloads the COSMOTE TV content ("data shower").





Novelties

Novel 3-level hierarchical vCDN solution incorporating MEC capabilities.

vCDN deployment as VNFs at MEC level to support the content delivery (storage and streaming).

Additional Edge server will be deployed on-board for serving the passengers even during disconnection periods.

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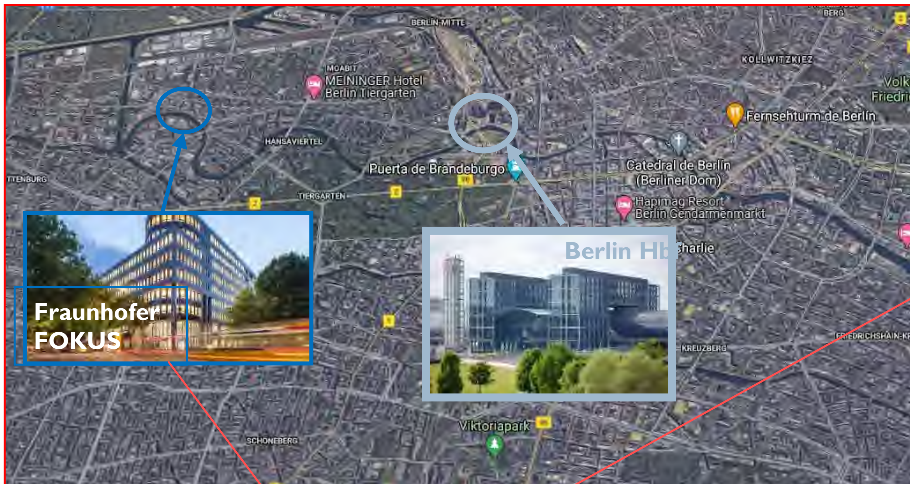
5G-VICTORI Berlin Facility, Germany

Berlin sites



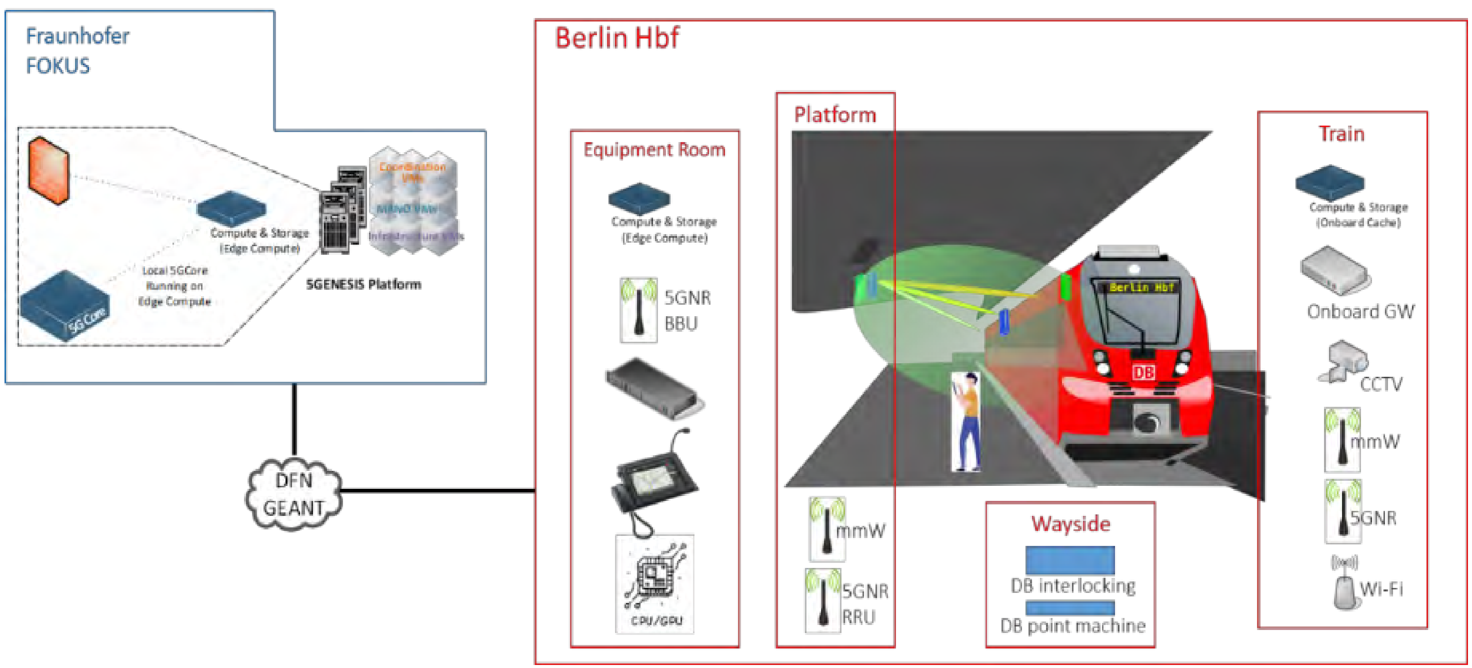
IHP Testfield

Annaberg-Buchholz Testfield

DB NETZE

test environment consisting of a test track and test vehicles with the aim of testing operational processes

5G-VICTORI Berlin set up



Rail Critical Services UC

Description and Services:

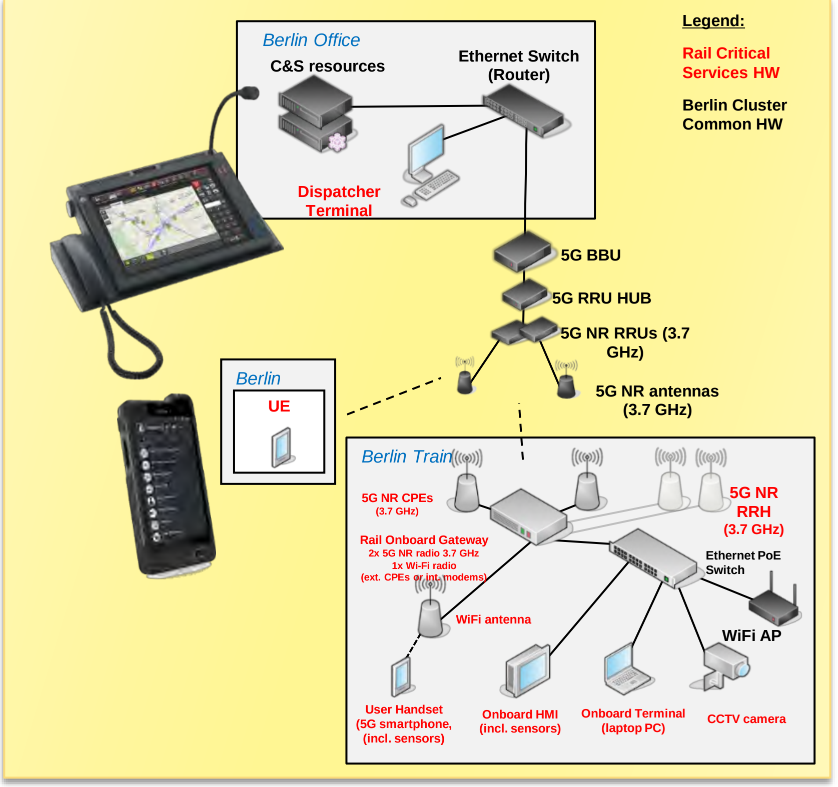
- **Train Control Signalling** based on emulated train signalling like CBTC, ETCS or FRMCS by Rail Signaling Traffic Generator between the train and Berlin Office endpoints.
- **Real-time High-Definition CCTV** transmission from train to the Berlin Office, from a train-mounted HD camera.
- **Mission-Critical (MC) Railway Telephony** like emergency group communication, operational private and group communication between driver,
- **Wayside point machine signaling** between an Interlocking and an Object Controller with its objects like Point Machine or a Signal.

Main KPIs:

- RCSg01
  - Round-trip-time less than 100 ms
  - Packet loss reation lower than 0.5 %
- RCSg02
  - Rail signaling traffic can use 200 kbps, regardless of background traffic

Novelties and key innovations

- Common platform for MC voice and video and other MC rail-related data and signalling services
- Onboard vertical services can be shown sharing the same 5G air interface without impact
- Softwarized solutions for



CDN services to moving train UC

Description and Services:

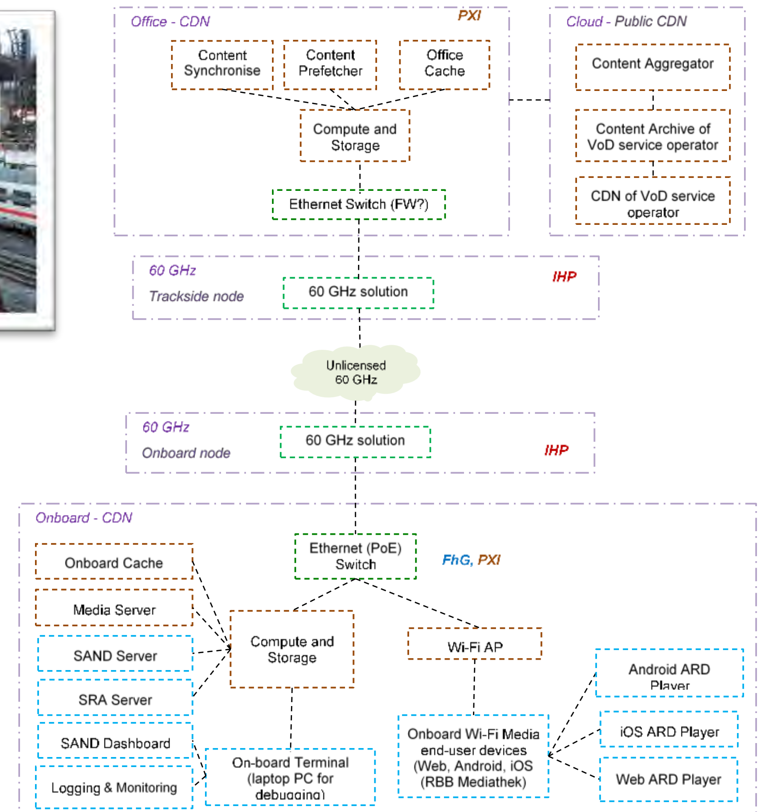
- Seamless integration of the 5G-VICTORI extended infrastructure towards the existing CDN infrastructure
- Consumption of linear live content – VoD content will be preloaded via a mmWave data shower

Main KPIs:

- Very high data rate
- RAN latency

Novelties and key innovations

- eMBB services efficiently provisioned under static and high mobility scenarios



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Thank you!

atzanakaki@phys.uoa.gr

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School of Business and Economics, Deree
The American College of Greece

Center of Excellence in Logistics, Shipping, and Transportation

My startup experience in the Shipping sector

4th Painless Summer School

Tuesday, May 10th 2022

George Kokosalakis

MARIE CURIE ACTIONS

Next 45′

- **Personal Path**
- **Navigating towards the "Great Idea"**
- … which may take a lot of time to emerge **(failures)**
- **Myths and Facts**
- **How will you succeed?**
- **Lessons Learned…** (Or not)
- **Opportunities**
- **Your questions…**

Talents

- **Engineer**
  - Civil and Environmental Engineering – Electrical Engineering & Computer Science
    - N.T.U.A.
    - M.I.T.
- **Manager**
  - Leaders for Manufacturing
    - M.I.T.
- **Entrepreneur**
  - New Ventures
    - Shipping
    - Construction
    - Renewable Energy
    - Wireless Sensor Networks

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Academic Appointments

Executive Director, Center of Excellence in Logistics, Shipping, and Transportation , The American College of Greece

Assistant Professor, School of Business and Economics, Deree, The American College of Greece

Senior Research Associate, Department of Civil and Environmental Engineering, University of Patras, Greece

Educational Counselor, Massachusetts Institute of Technology, USA

Entrepreneurial Appointments

Founder & ….:

- **Technical Manager**, Shipmanagement Company
- **Technical Director**, Ship Repair Management Company
- **Consultant Engineer**, Instrumentation & Wireless Sensor Networks
- **Director**, Construction Company Public & Private Works
- **Vice President**, Renewable Energy Production Company

The Dream #1

Before graduation…

- I was desperately searching for a **BRIGHT IDEA…**
- Create a **seminal** dissertation

× Failed (#1)

✓ I did graduate!

➢ ***Innovation is Incremental Improvement of the State of the Art***

The Dream #2

Upon graduation (USA)…

- Wanted to create my **Own Entrepreneurial Venture**
- Based on my **doctorate research & 3 patents**
- Designing, building, and deploying Instrumentation & Wireless Sensor Networks

✗ Failed (#2)

✓ However, I worked in the same field for other companies

➢ ***Work Experience is not mandatory, but certainly useful!***

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The Dream #3

Upon return to Greece…

- Wanted to live in Greece…but work abroad…
- Build a successful career in Shipping (Also Energy & Construction Industries)

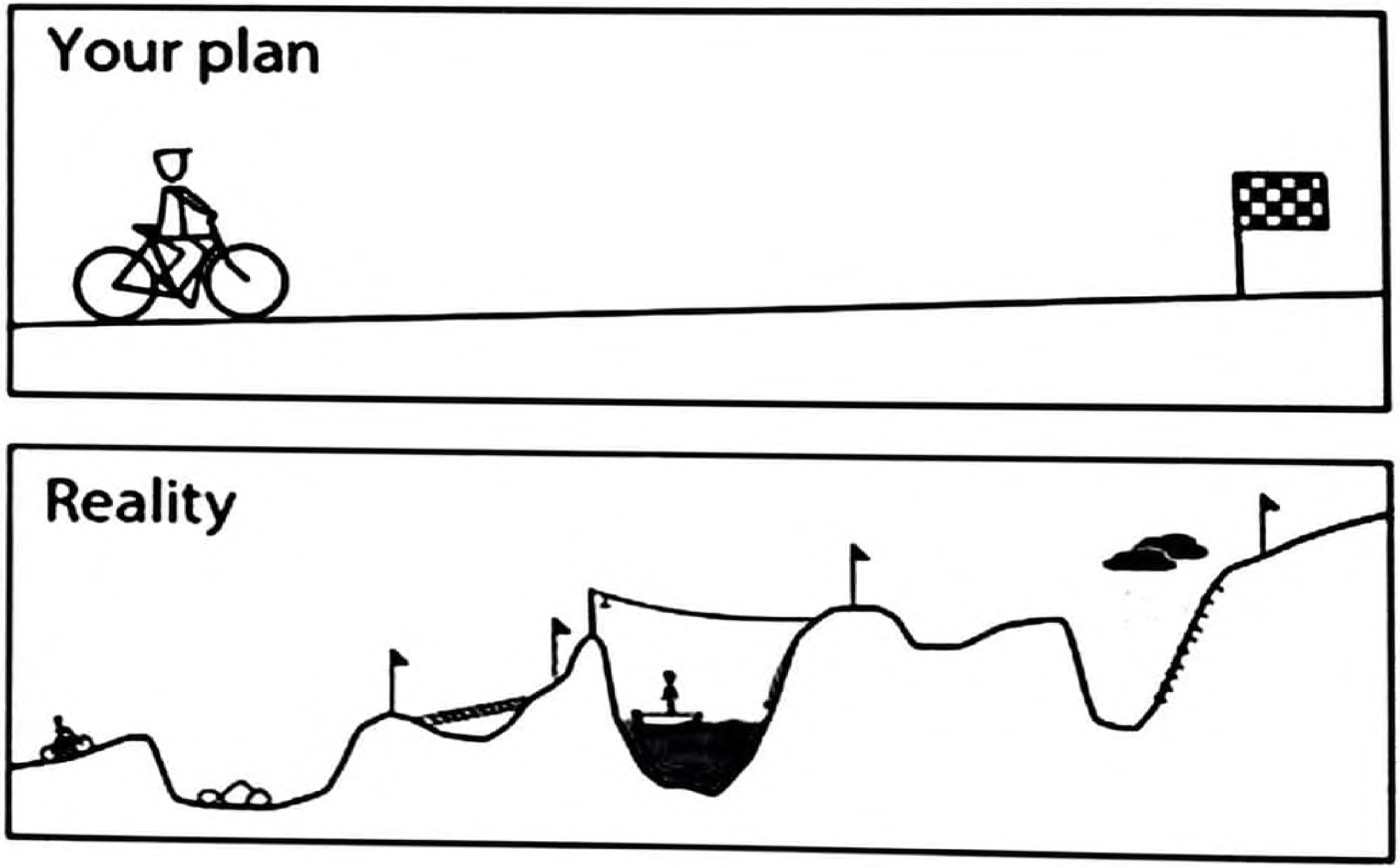
- Generate wealth and attract attention

× Failed (#3), (#4), & (#5)

✓ Currently on the 3rd Iteration

➢ ***Keep going…***

The Road to Start-Up



https://vacationtracker.io/blog/startups-can-benefit-from-serverless/

Myths & Facts

- ×You need **a lot of money** to start your business.
- ×I need a **Great Idea**.
- ×The bigger the **risk**, the greater the **reward.**
- ×A business plan is required for success.
- ×Entrepreneurship is for the **young** and reckless.
- ×Entrepreneurship cannot be **taught**.

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Creating Opportunity

Don’t Wait for an Opportunity…

Create It!!!

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Creating Opportunity

- **Creativity is the key**
- **Idea vs. Opportunity**
  - Opportunity = Idea with market potential
- **Train yourselves**
  - Look for problems
  - Identify solutions

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Entrepreneurial Skills

- **Empathy**
  - View world from many different perspectives
- **Integrative thinking**
  - Recognize contradictory options, Improve existing solutions
- **Optimism**
  - There is always a better solution available
- **Experimentation**
  - Iterate on ideas to achieve optimum
- **Collaboration**
  - Interdisciplinary thinker and knowledge base

How will you make it?

- **Identify current problems around you?**
  - Observe, Feel, Navigate, Experiment…

    "can I solve this?"
- **Personal Preferences**
  - Passion
  - Knowledge
  - Skills
  - What am I good at?

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How will you make it?

- **Creativity**
- **Study successful** (and not) **Entrepreneurs**
  - Learn from their experience…
- **Persistence**

Keep going...

Upfold YOUR superhero

Lessons Learned... so far

- **Accept Risks but Assess them**
  - Legal Environment
  - Financial Environment
    - Market condition and expectations
    - Capital availability
  - Political Environment
    - Instability
    - War
  - Founding team
  - Personal restrictions
  - Proper timing
    - Market
    - Technology

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Lessons Learned... so far

- Capital alone cannot guarantee success of an idea
- **Be ready to fall**…
- But have strength to rise again… **Don’t Give Up!**
- The end of an idea/company is not the end of life…

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Maritime Industry vs. Entrepreneurship

- **Maritime Industry**
  - × Tough for newcomers
  - × Established relationships
  - × Resource Intensive
  - × Heavily Regulated

However, …

- ✓ it is **Desperate for Innovation**
- ✓ It operates in the **Global Environment**
- ✓ It offers great **Wealth opportunities**

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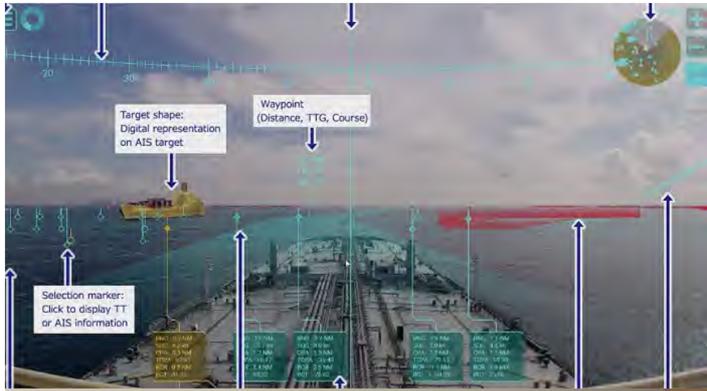
Lots of opportunities… a few examples

- **Digital Transformation – Industry 4.0**
  - Real time control systems
  - Augmented reality
  - User Interface
  - Big Data Storage and Analysis
  - Cyber – Physical Systems
  - Autonomous systems
  - Cyber Security and Data Protection
  - Internet of Things
  - Remote applications (Telemedicine, Online Surveys, etc)



Images Courtesy of: Furuno, Bureau Veritas

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Lots of opportunities… a few examples

- **Sustainability & Climate Change**
  - Energy & Decarbonization
    - Alternative Fuels
      - Production, Storage, Distribution, Usage
    - Alternative Sources of Energy
      - Renewable Energy Harvesting
    - Hybrid systems

Images Courtesy of: DNV-GL, SkySails

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Ideas !
Questions ?

Thank you for your attention!

George Kokosalakis
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ARIADNE: A Synthesis of 3 Critical 6G Enablers

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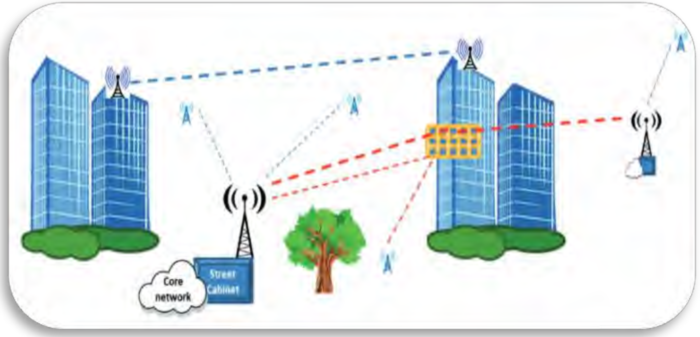
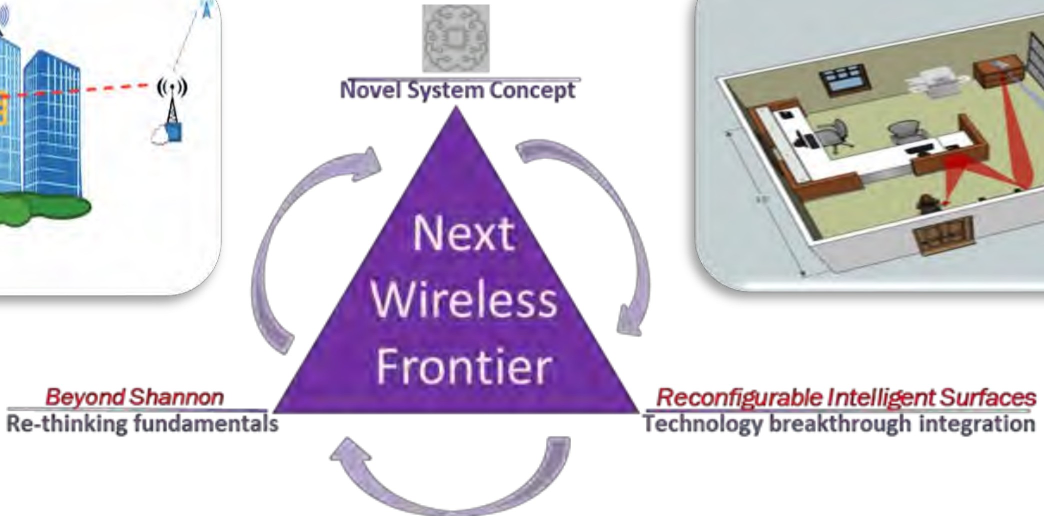
PAINLESS 4th Summer School, 9 May 2022

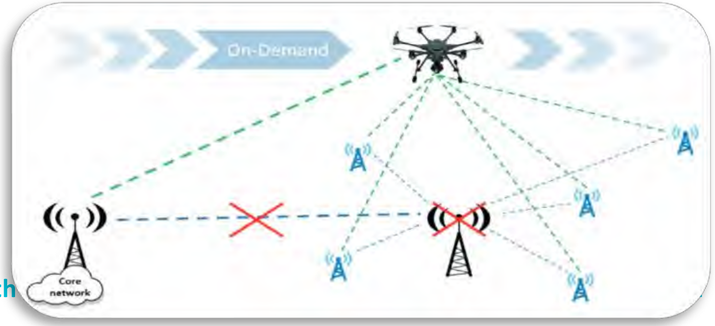
ict-ariadne.eu **contact@ict-ariadne.eu** ict-ariadne

ARIADNE is a three years Research and Innovation action / project under the EU program Horizon 2020 (Grant Agreement no. 871464) started on 1 November 2019

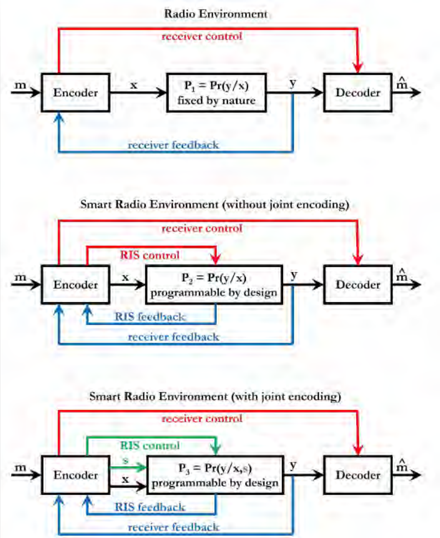
ARIADNE System Concept

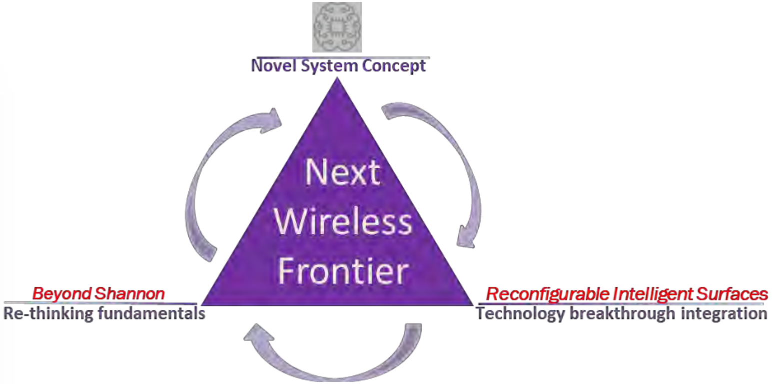


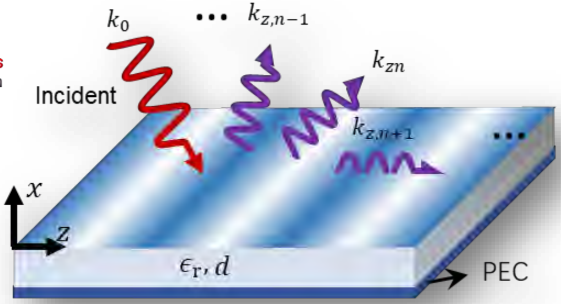




ARIADNE System Concept





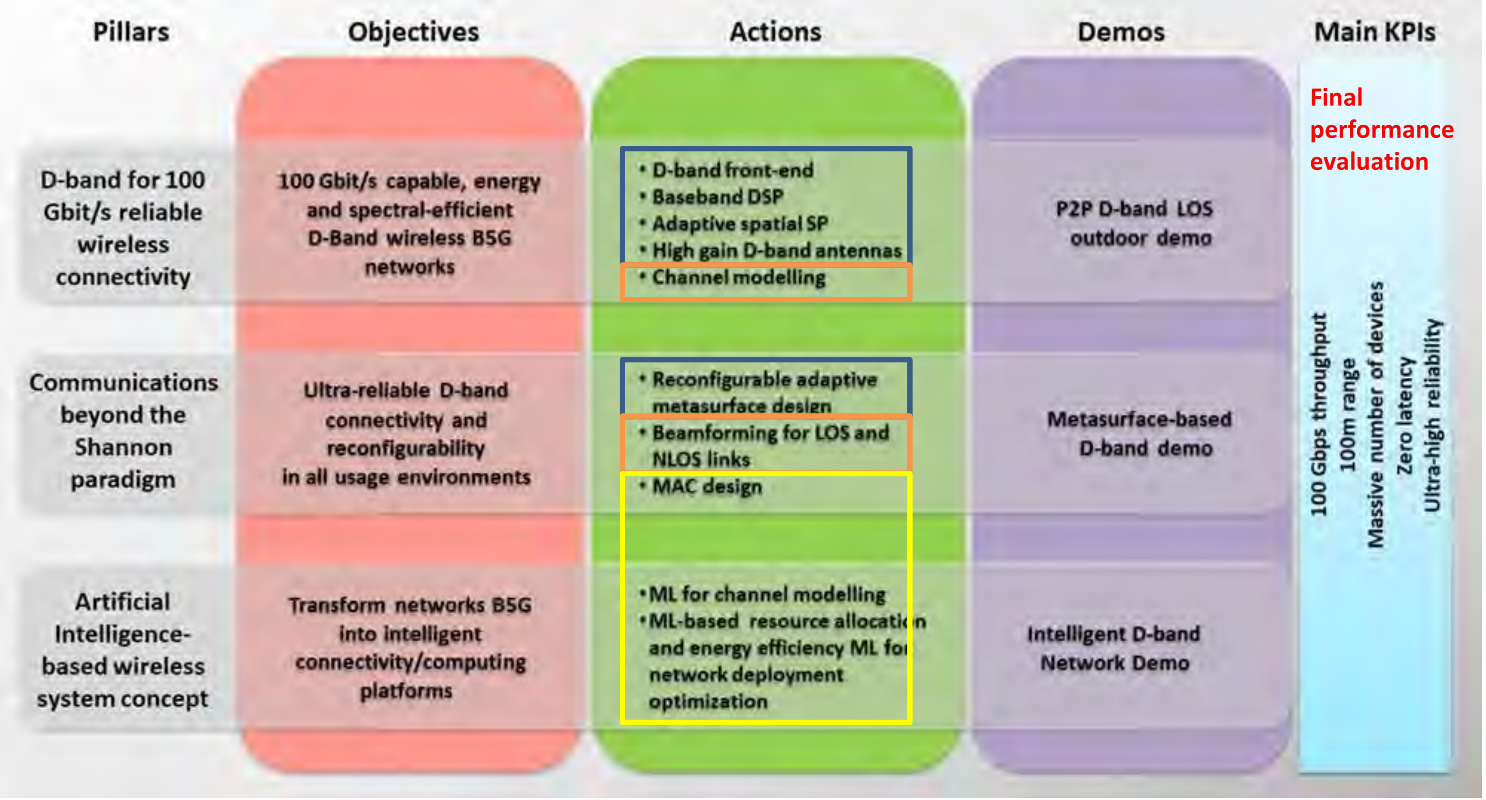


ARIADNE Objectives

Design completed

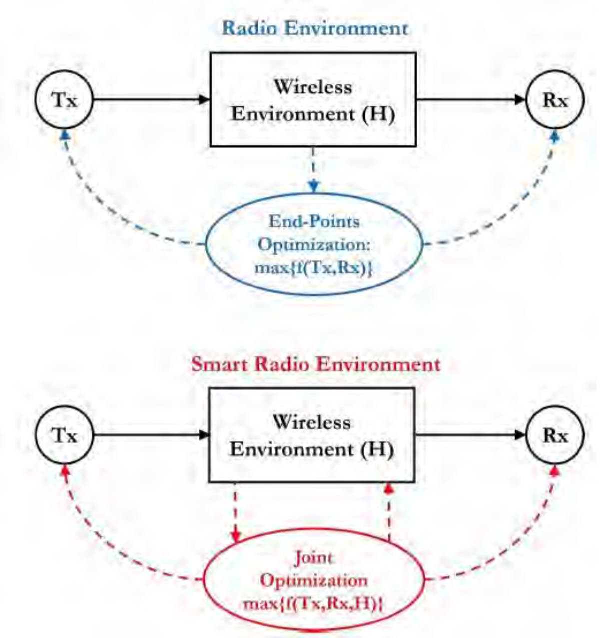
Significant progress

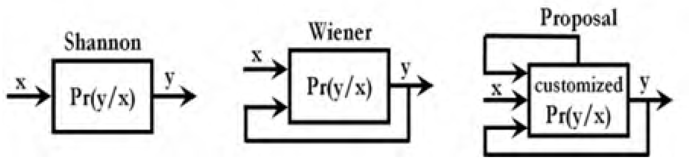
Ongoing as planned



ARIADNE

Beyond Shannon Communications: the dawn of EM Information Theory

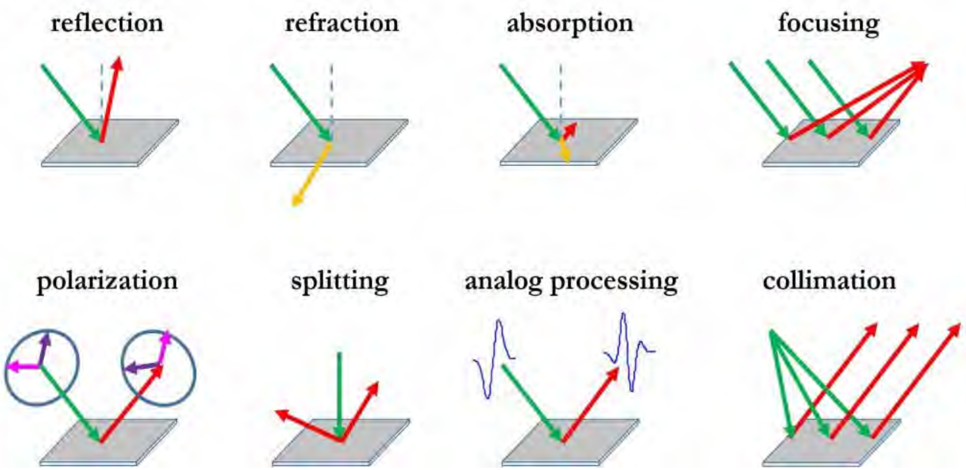




By jointly optimizing the transmitter, the receiver, <u>and the environment</u>, the channel capacity of a point-to-point wireless communication system can be further improved.

Source: M. Di Renzo et al., "Smart Radio Environments Empowered by Reconfigurable Intelligent Surfaces: How It Works, State of Research, and The Road Ahead," in IEEE Journal on Selected Areas in Communications, vol. 38, no. 11, pp. 2450-2525, Nov. 2020, doi: 10.1109/JSAC.2020.3007211.

A RIS-based Wireless: the dawn of the Internet of Materials



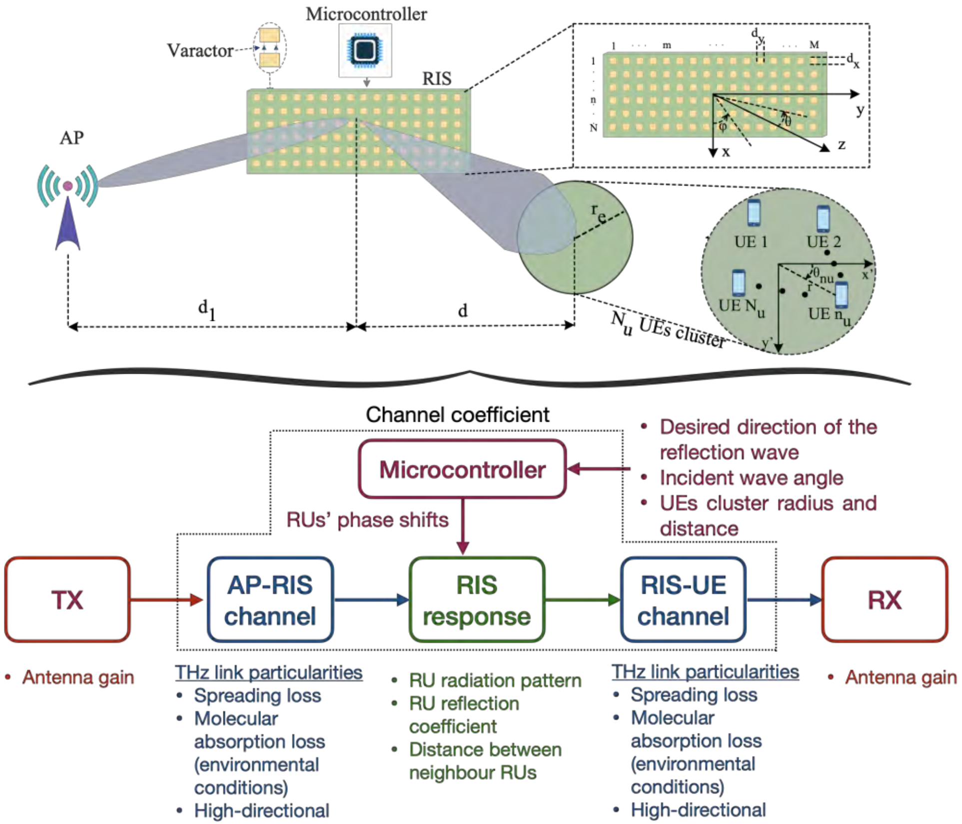
Source: M. Di Renzo et al., "Smart Radio Environments Empowered by Reconfigurable Intelligent Surfaces: How It Works, State of Research, and The Road Ahead," in IEEE Journal on Selected Areas in Communications, vol. 38, no. 11, pp. 2450-2525, Nov. 2020

RIS can introduce an intelligent filter offering:

- ✓ Power transfer / relaying
- ✓ Reliable NLoS (indirect link)
- ✓ Interference mitigation
- ✓ Diversity
- ✓ Beamforming
- ✓ (any filter 'synthesized'

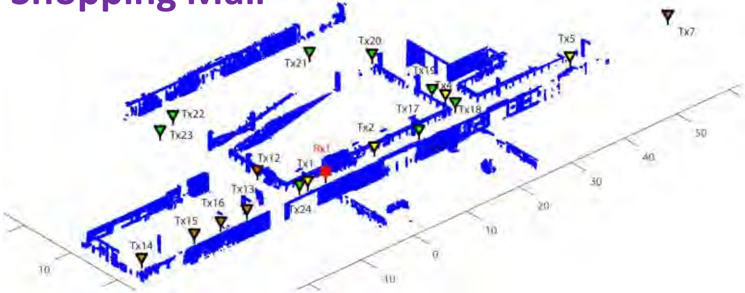
by the surface EM functionalities)

A RIS-based Wireless Architecture

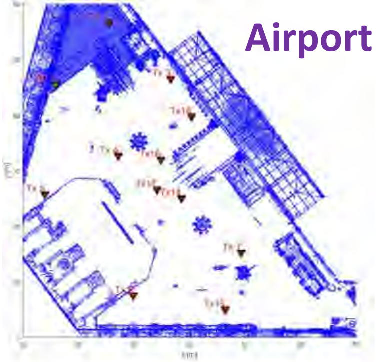


D-band connectivity

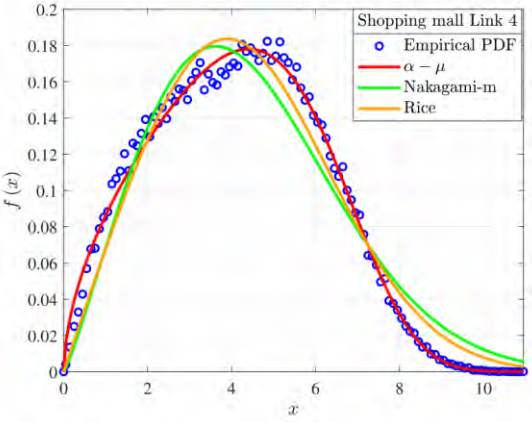
Shopping Mall

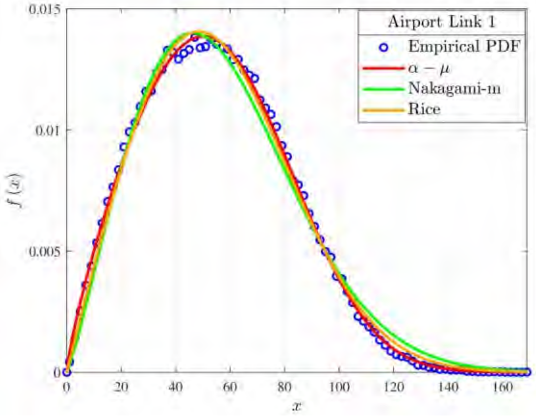


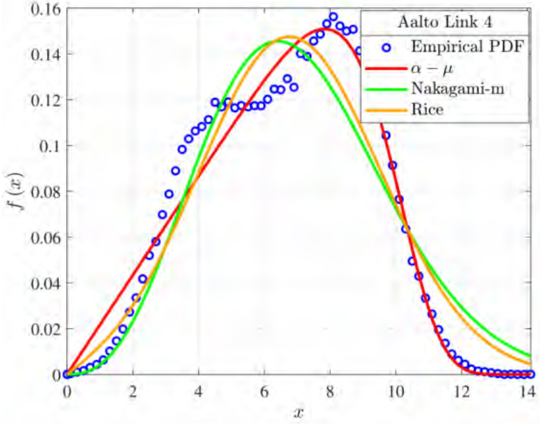
Airport



Aalto University





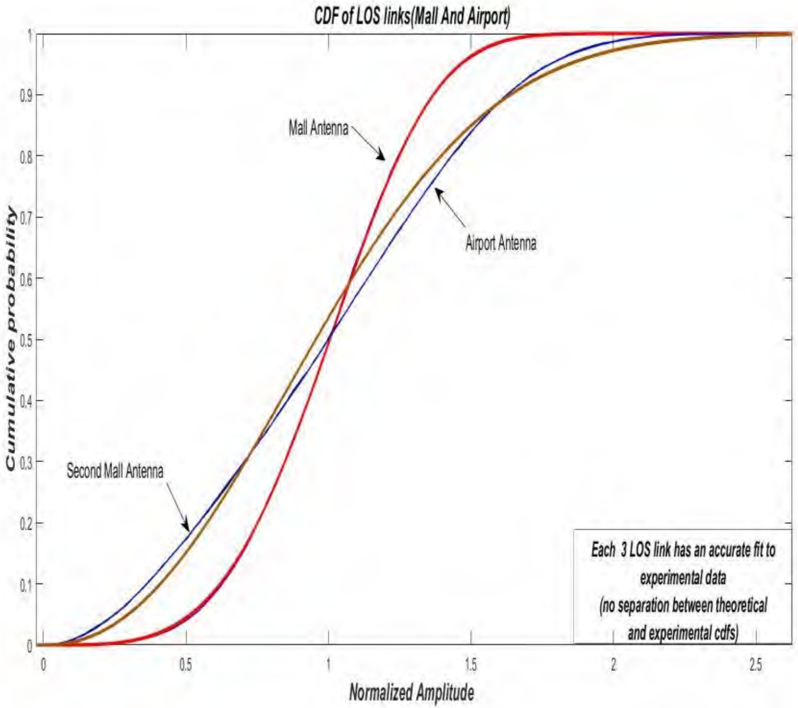


All measurements (by Aalto University) were conducted at $f = 142$ GHz with a bandwidth of 4 GHz.

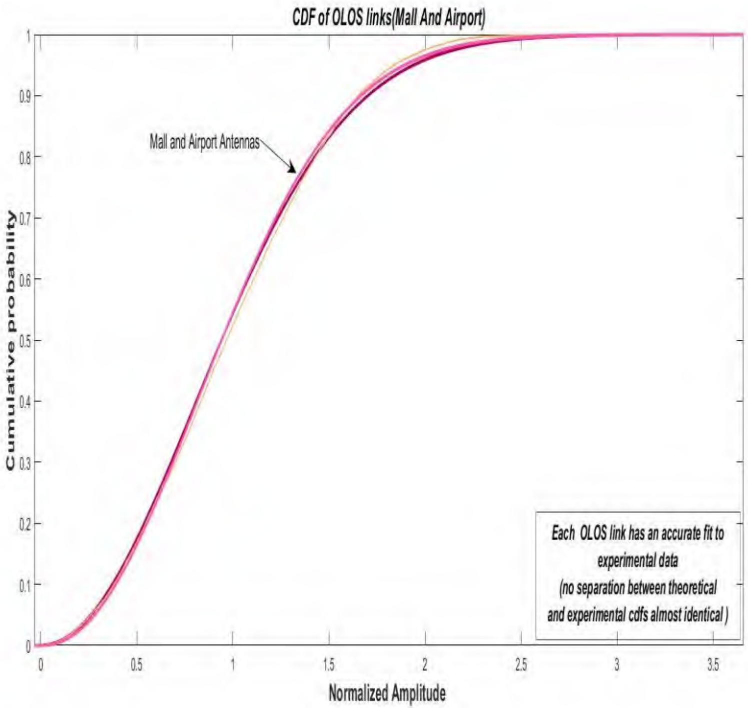
E. Papasotiriou et al. , “An Experimentally Validated Fading Model for THz Wireless Systems”, August 2021, Scientific Reports

D-band connectivity (2)

Weibull vs LOS data

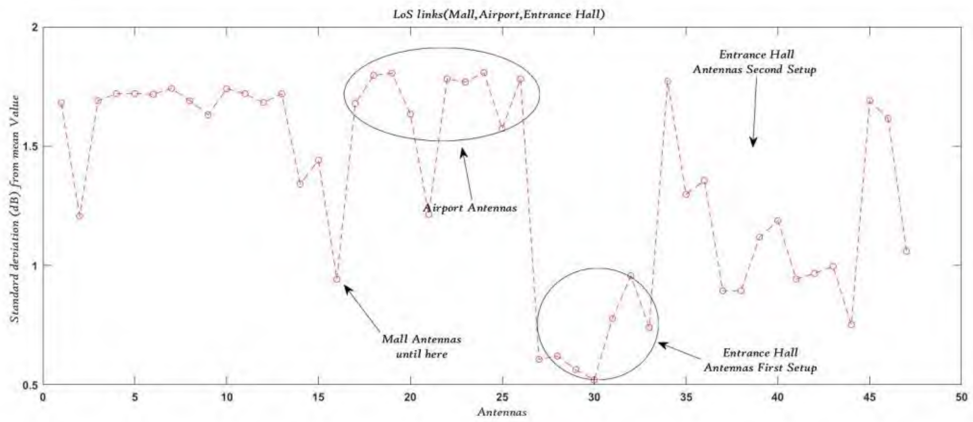


Nakagami-m vs NLOS data



D. Selimis et al. “Initial investigation of D-band small-scale fading statistics”, EUCAP 2021

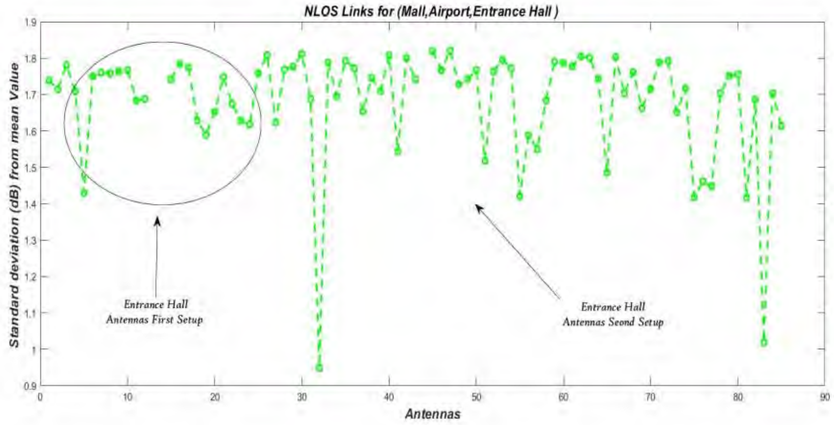
D-band connectivity (3)



Standard deviation of small-scale fading

LOS links

NLOS links



D-band Path-loss modeling

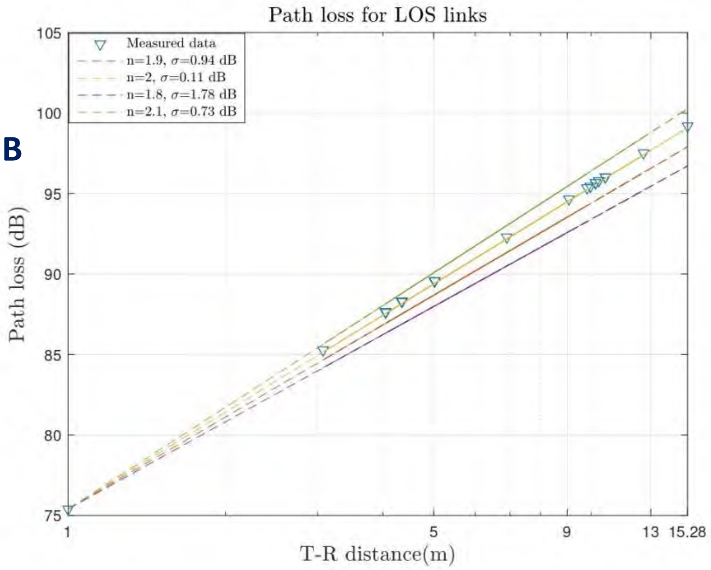
- 1m close-in (CI) free space path loss model

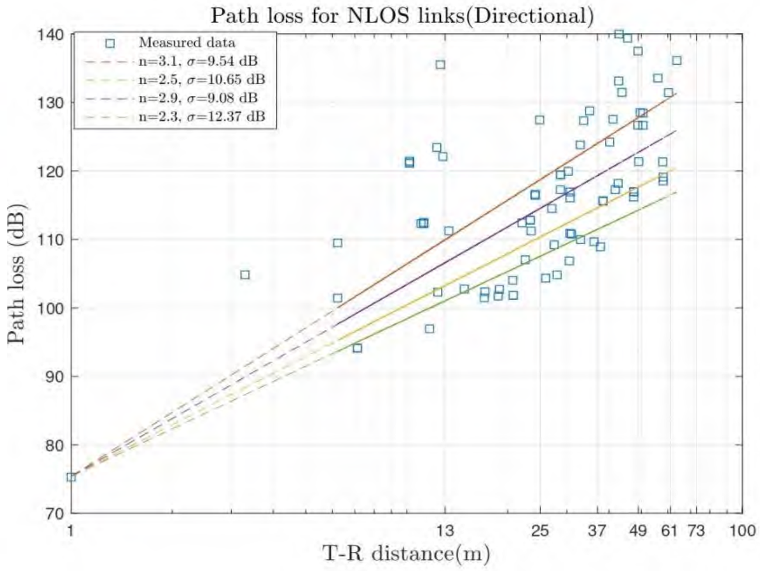
$$PL\,(f_c, d) = \mathrm{FSPL}(f_c, do) + 10\,n\,log10\left(\frac{d}{do}\right) + x$$

Examples of FSPL at 10m
- f = 6 GHz, FSPL = 68 dB
- f = 28 GHz, FSPL = 81.4 dB
- f = 140 GHz, FSPL = 95.4 dB

PL: path losses
FSPL: indicates free space path losses at reference distance do = 1m
***n* : Path loss exponent**
x : Large scale shadow fading in dB, with standard deviation σ (in dB)

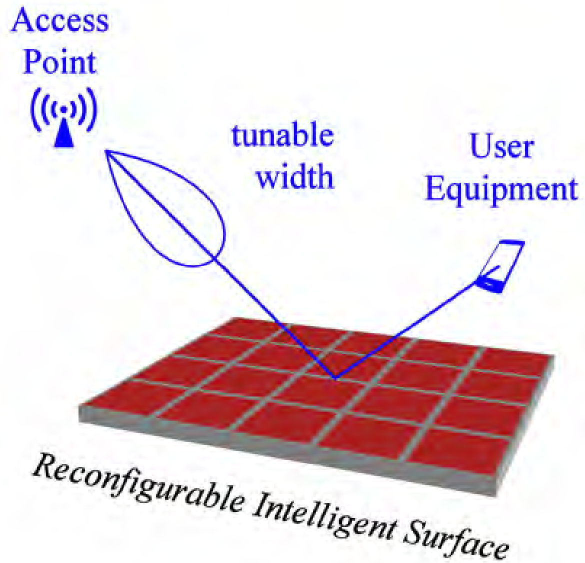
***n*=2**
***σ*=0.11dB**

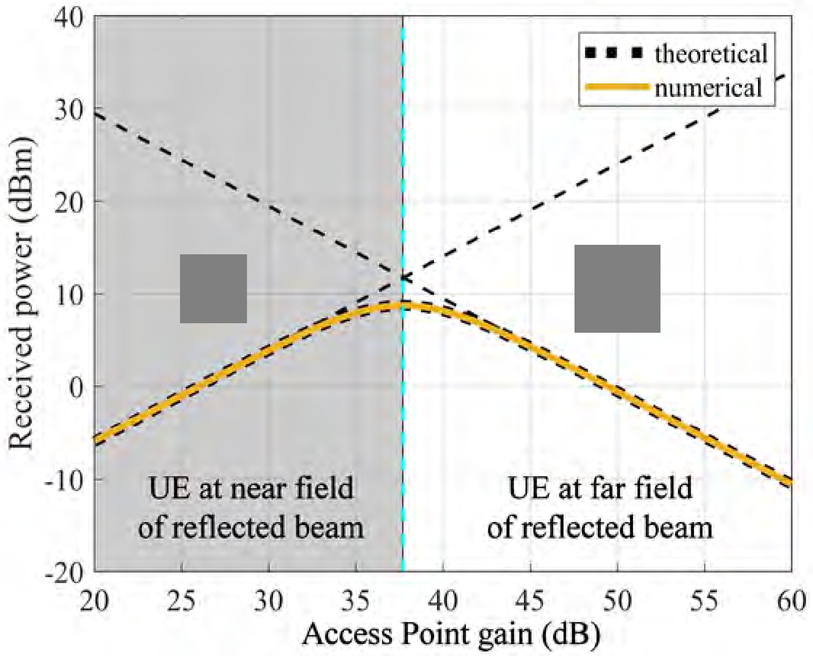




***n*=2.9**
***σ*=9.08 dB**

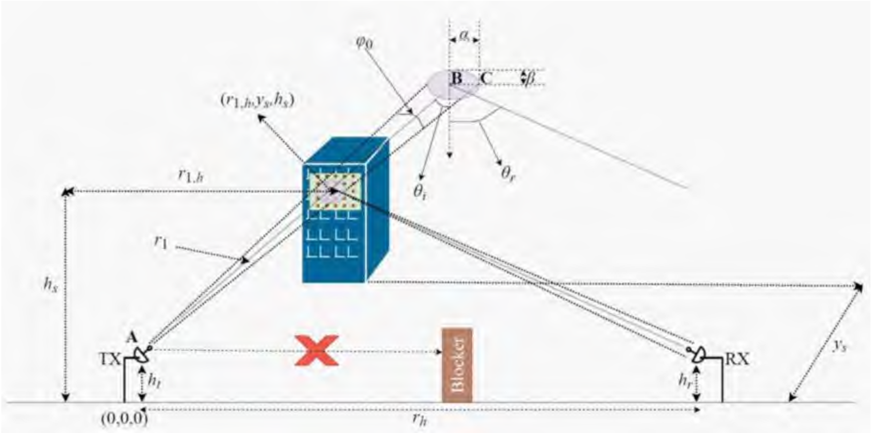
BF efficiency in RIS-aided links





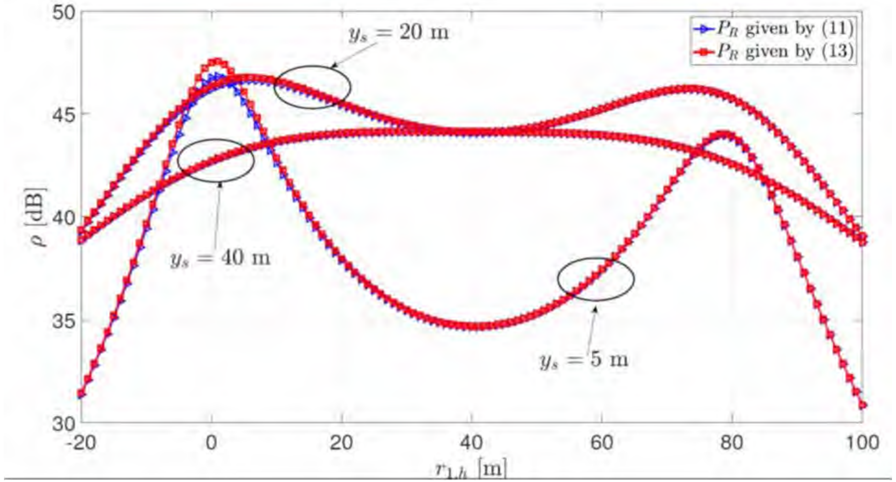
G. Stratidakis, S. Droulias and A. Alexiou, "Analytical Performance Assessment of Beamforming Efficiency in Reconfigurable Intelligent Surface-Aided Links," IEEE Access, vol. 9, pp. 115922-115931, 2021, doi: 10.1109/ACCESS.2021.3105477.

Optimal placement of RISs

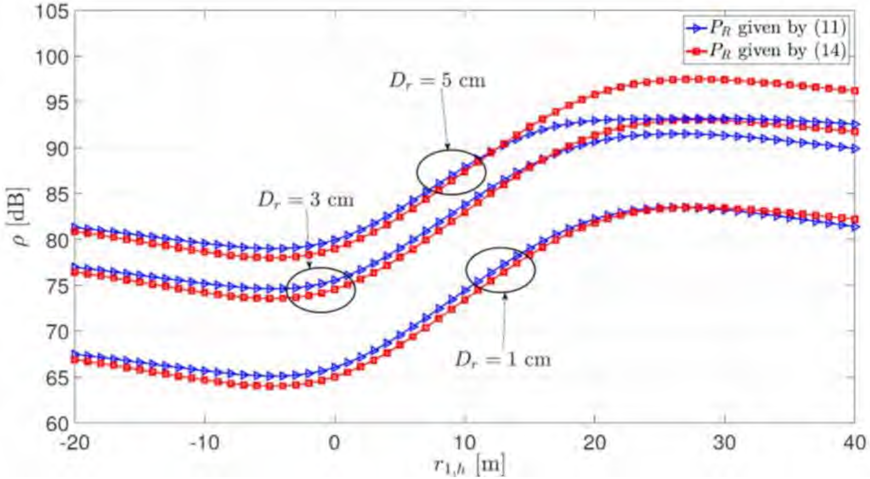


K. Ntontin et al. "Reconfigurable Intelligent Surface Optimal Placement in Millimeter-Wave Networks", IEEE Open Journal of the Communications Society, 2021

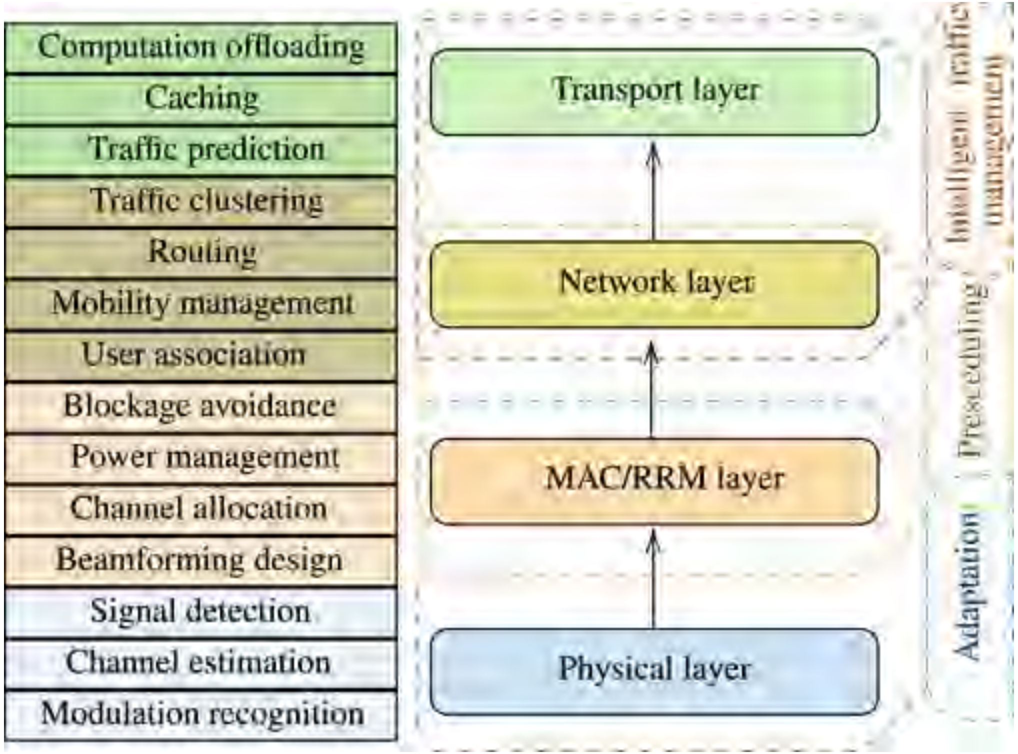
Main lobe footprint larger than RIS



Main lobe footprint smaller than RIS

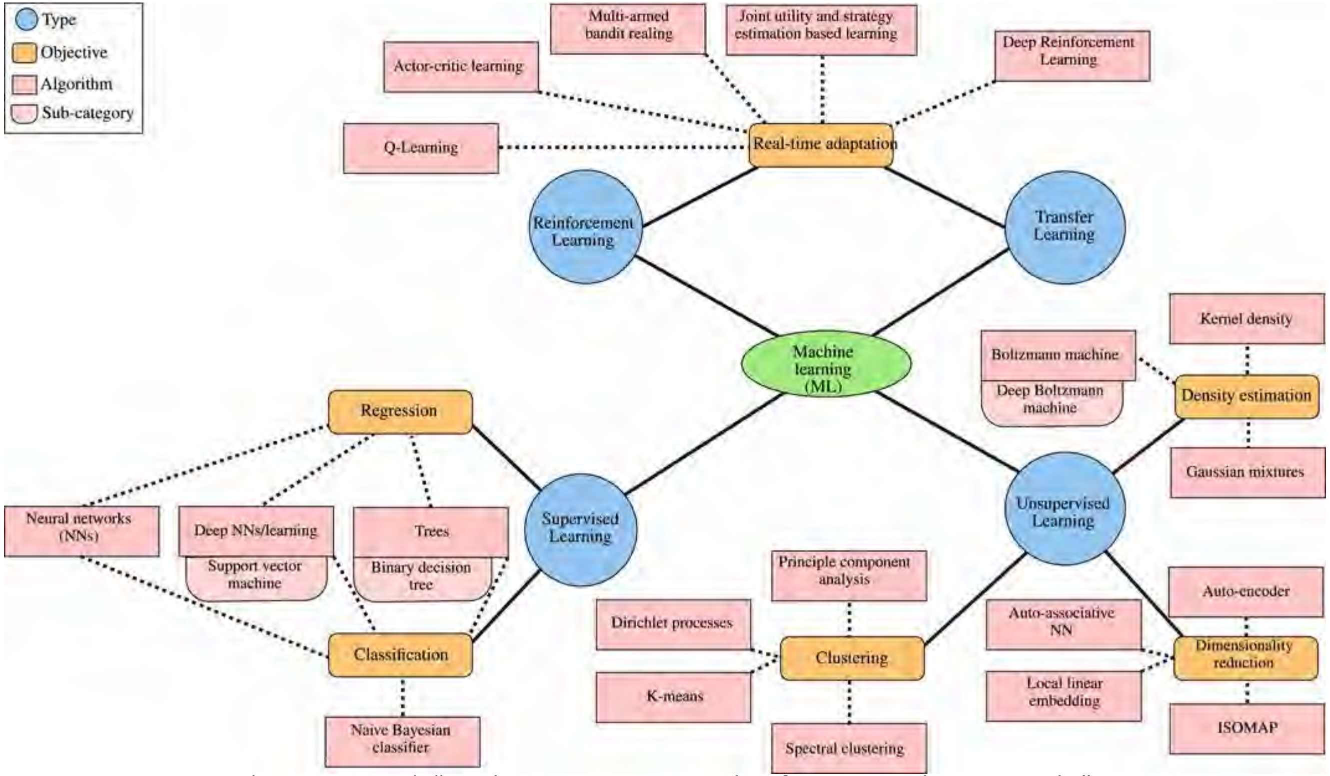


AI/ML-powered Network Architecture



A.-A. Boulogeorgos et al. "Machine Learning: A Catalyst for THz Wireless Networks", Front. Comms. Net., 09 September 2021, https://doi.org/10.3389/frcmn.2021.704546

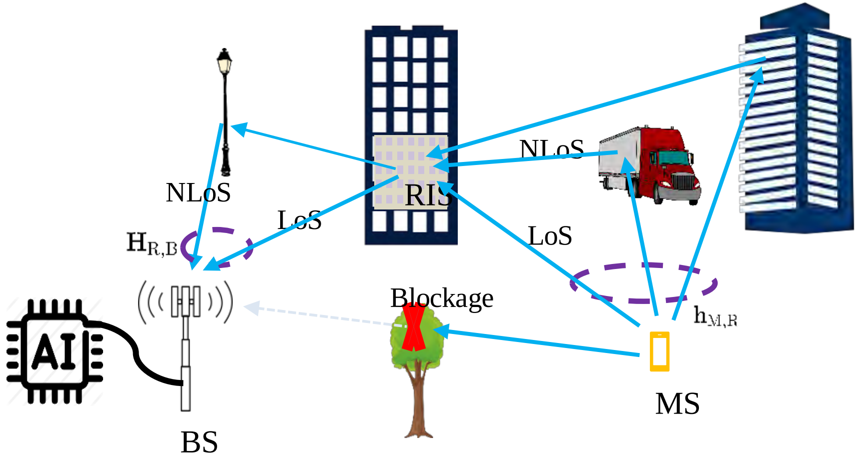
AI/ML-powered Network Architecture (2)



A.-A. Boulogeorgos et al. “Machine Learning: A Catalyst for THz Wireless Networks”, Front. Comms. Net., 09 September 2021 | https://doi.org/10.3389/frcmn.2021.704546

Estimating RIS-Aided MISO Channels via Deep Unfolding (DU)

System Model



- No direct MS-BS channel
- RIS is a uniform linear array (ULA)
- Parametric channel model (inherent sparsity)
- RIS is purely passive with no baseband processing units

Deep Unfolding for Channel Estimation (CE)

W=combining matrix, H_c=cascaded channel, $\bar{\Omega}$=RIS phase control matrix (measured) , N = noise

- Collection of pilot signals

$$\mathbf{Y} = \mathbf{W}^{\mathsf{H}}\mathbf{H}_c\bar{\mathbf{\Omega}} + \mathbf{W}^{\mathsf{H}}\mathbf{N},$$

Assumptions

$$s[1] = \cdots = s[K] = 1$$
$$\mathbf{W}[1] = \cdots = \mathbf{W}[K] = \mathbf{W}$$

- Vectorization

$$\mathbf{y} = (\bar{\mathbf{\Omega}}^{\mathsf{T}} \otimes \mathbf{W}^{\mathsf{H}})\mathbf{h}_c + \mathbf{n},$$

known

$$\mathbf{h}_c = \mathrm{vec}(\mathbf{H}_c)$$
$$\bar{\mathbf{\Omega}} = [\boldsymbol{\omega}[1], \cdots, \boldsymbol{\omega}[K]]$$

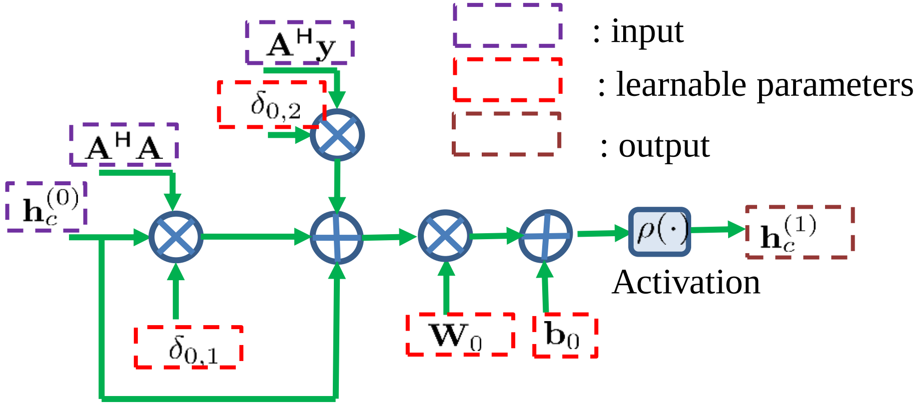
- Definition of measurement matrix

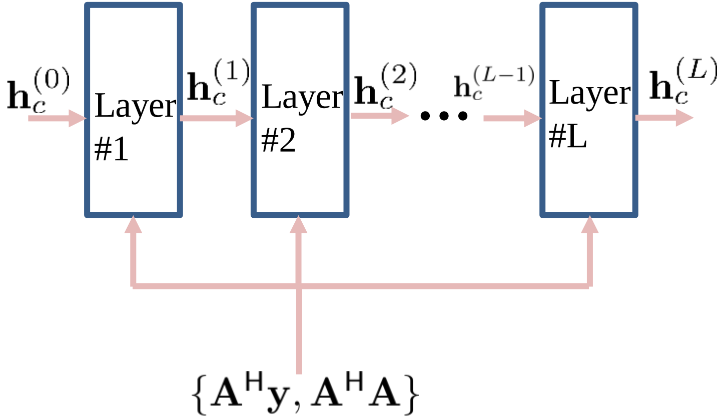
$$\mathbf{A} = \bar{\mathbf{\Omega}}^{\mathsf{T}} \otimes \mathbf{W}^{\mathsf{H}}$$

- Reformulation of $\mathbf{y}$

$$\mathbf{y} = \mathbf{A}\mathbf{h}_c + \mathbf{n}$$

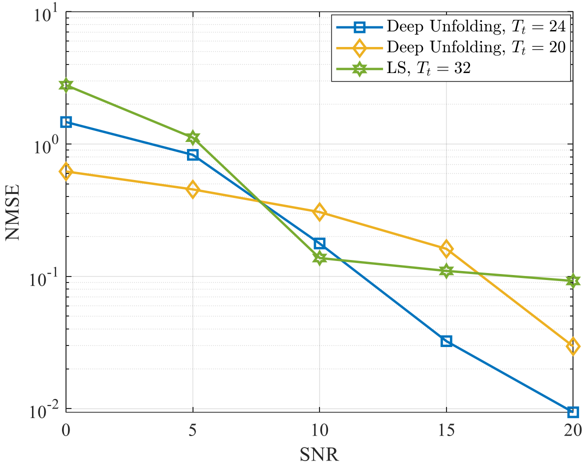
- Estimation of $\mathbf{h}_c$
  - Conventional CE method: LS
  - New CE method: data-driven deep unfolding





CE via DU simulation results

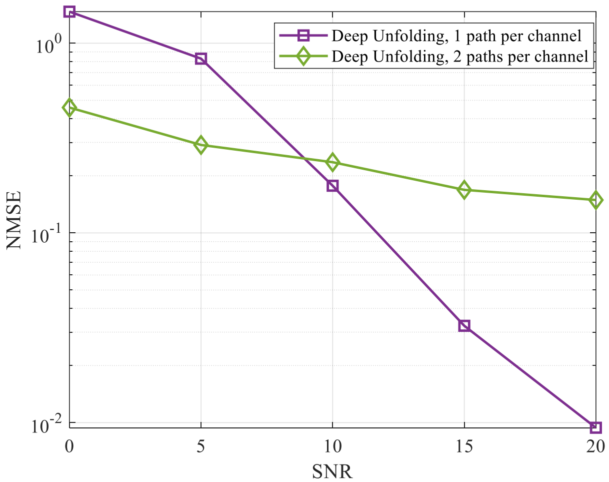
2×1 MISO, RIS:32



Effect of training overhead

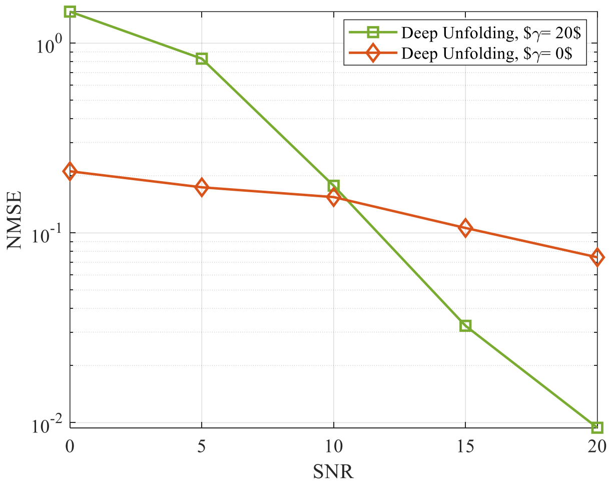
- DU can outperform LS with less overhead

2×1 MISO, RIS:32



Effect of number of paths

- Performance saturates when no. of paths increase



Effect of training SNR

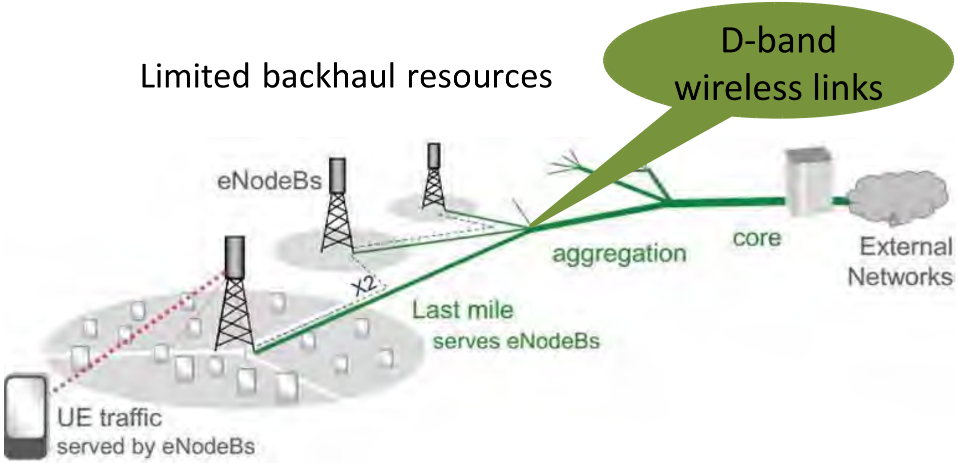
- Low training SNR brings better results in low SNR regime, and vice versa.

No. of training samples: 100.000	No. of epoch: 40	No. of layers: 15
No. of testing samples: 10.000	Optimizer: Adam	Loss function: NMSE

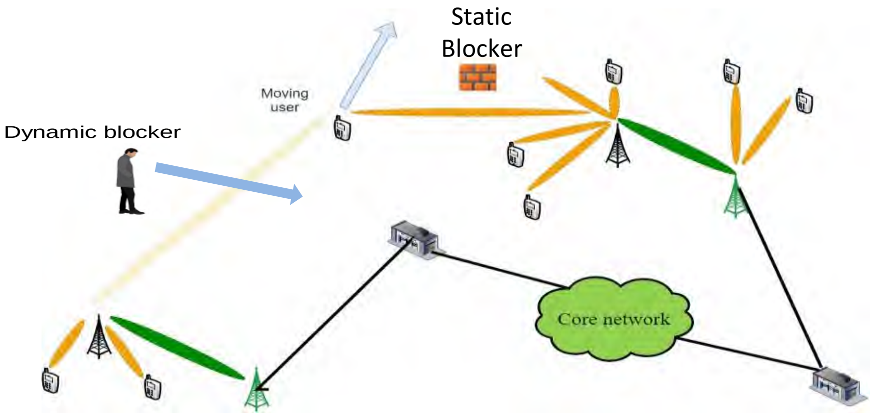
User association (UA) motivation in D-band networks

Directional communication due to high path-loss

Limited backhaul resources



Sensitivity to blockage phenomena



D. C. Mur, et al, "AI and ML – Enablers for Beyond 5G Networks", 5G PPP Technology Board, v. 1.0, May 2021.

User association Problem Formulation & Solution

Cell-User assignment of User Equipments (UE) to Access Points (AP) requires resource allocation in dense network models that face LoS blockages

➢Objectives as **C**onstraints

C1: Uniquely associate a UE to an AP (1:1)
C2: An AP can be assigned multiple UEs (1:m)
C3: Minimize overuse of AP's resources, which are required by all assigned UEs
C4: Avoid or minimize LOS blockages between UE and AP

The ML solution had following properties:

- All UEs were associated to APs
- Solution used only 99 out of 125 APs, hence it is energy efficient!
- Slightly unbalanced as 22 APs are slightly overloaded
- Obedience of LOS constraint
  - For 86% UEs, partial blockages are fully avoided. For rest 14% UEs, blockages minimized to 1
- ML model (Gradient Boosted Tree) was trained on solutions found by Late Acceptance metaheuristic optimization
- On average: 7.5 UEs assigned to 1 AP

UEs (Total: 741)			APs (Total: 125)		
Allocated	LOS Obeyed	1 partial blockage	Used	Utilization: OK	Utilization: Overloaded
741	635	106	99	77	22

AI/ML Framework for Autonomous Management of Directional Connectivity

- **AI/ML Framework:** to solve planning problems for connectivity & resource allocation with hybrid outcome: 1) Metaheuristic solution 2) ML model and its predicted solution
- **Problem Solved:** Cell-User assignment (joint resource allocation & LoS blockage minimization) of Users Equipment (UE) to Access Points (AP) in dense networks facing blockages
- **Result:** Optimal UE-to-AP assignments (directional connectivity) by Metaheuristics & ML predictions

Legend:

Surrounding Dots are UEs

Purple Dot = UE in SouthEast

Skyblue Dot = UE in SouthWest

Orange Dot = UE in NorthWest

Peach Dot = UE in NorthEast

Central Dots are APs

Gray Dot = AP not overloaded

Red Dot = Overloaded AP

Line color shows LoS blockages

Green line = 0 partial blocker

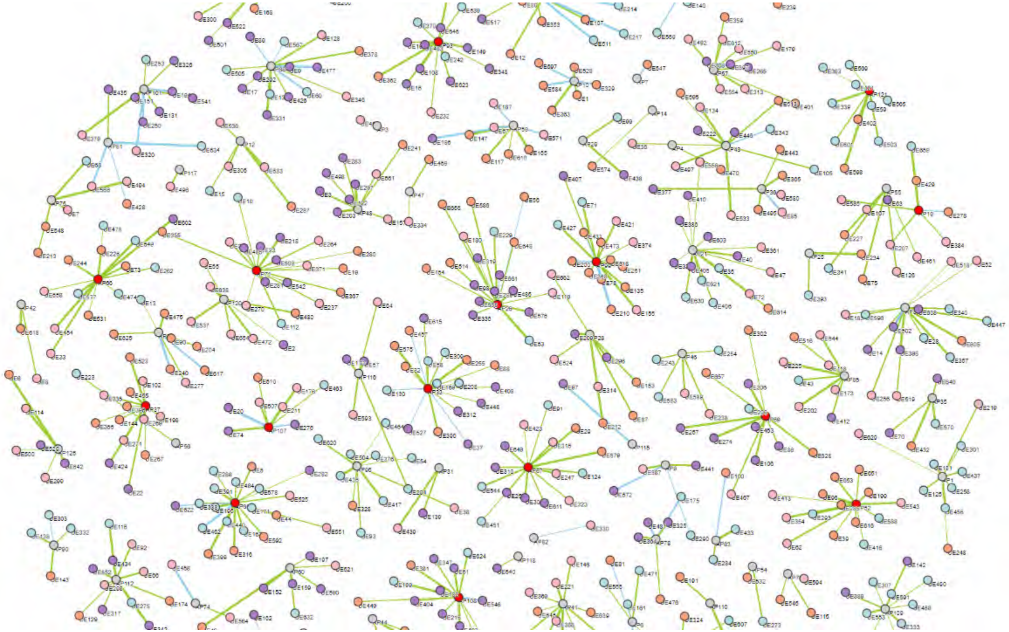
Blue line = 1 partial blocker

Red line = 2 partial blockers

Line Length = distance from AP

Line Width = resource (bandwidth) required by UE

Tooltip: provides further information of AP or UE



Concluding remarks

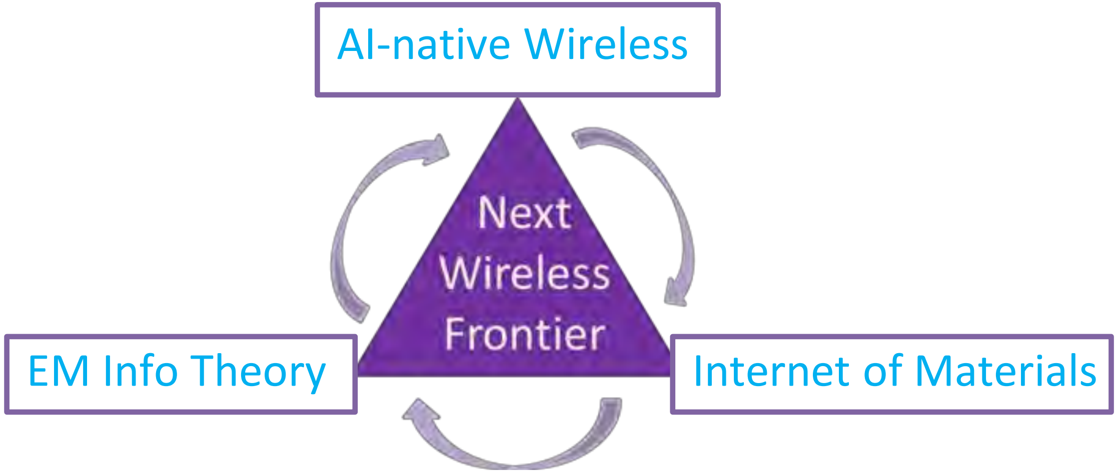
- Realizing ARIADNE vision involves rethinking of wireless fundamentals (beyond Shannon), inventing breakthrough technology enablers (RIS at D-band) and devising a novel AI/ML based system concept

- Delivering the ARIADNE system concept requires disruptive innovations that will highly impact architecture wrt: TxRx design, algorithms and signalling, MAC protocols, resources and network management and offline/real-time optimization

- ARIADNE targets 'smartness' at various levels: HW component, modelling, signalling, algorithm, management, optimization

- Key success factor: adequately address ARIADNE system technology particularities (D-band propagation, misalignment, blockage, etc) and usage scenarios challenges (backhaul/fronthaul, NLOS connectivity, adhoc/moving topology)

ARIADNE 6G Innovations and Impact



Special Issue of IEEE J-SAC on Beyond Shannon Communications Guest Edited by ARIADNE
Submission Deadline: 1 August 2022

Thank You!

ARIADNE

ict-ariadne.eu

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ict-ariadne

ARIADNE is a three years Research and Innovation action / project under the EU program Horizon 2020 (Grant Agreement no. 871464) started on 1 November 2019

"Entrepreneurial Tales: From concept to commercialization- challenges and realities".

Dr. Katerina Voutsina

Assistant Professor in Entrepreneurship

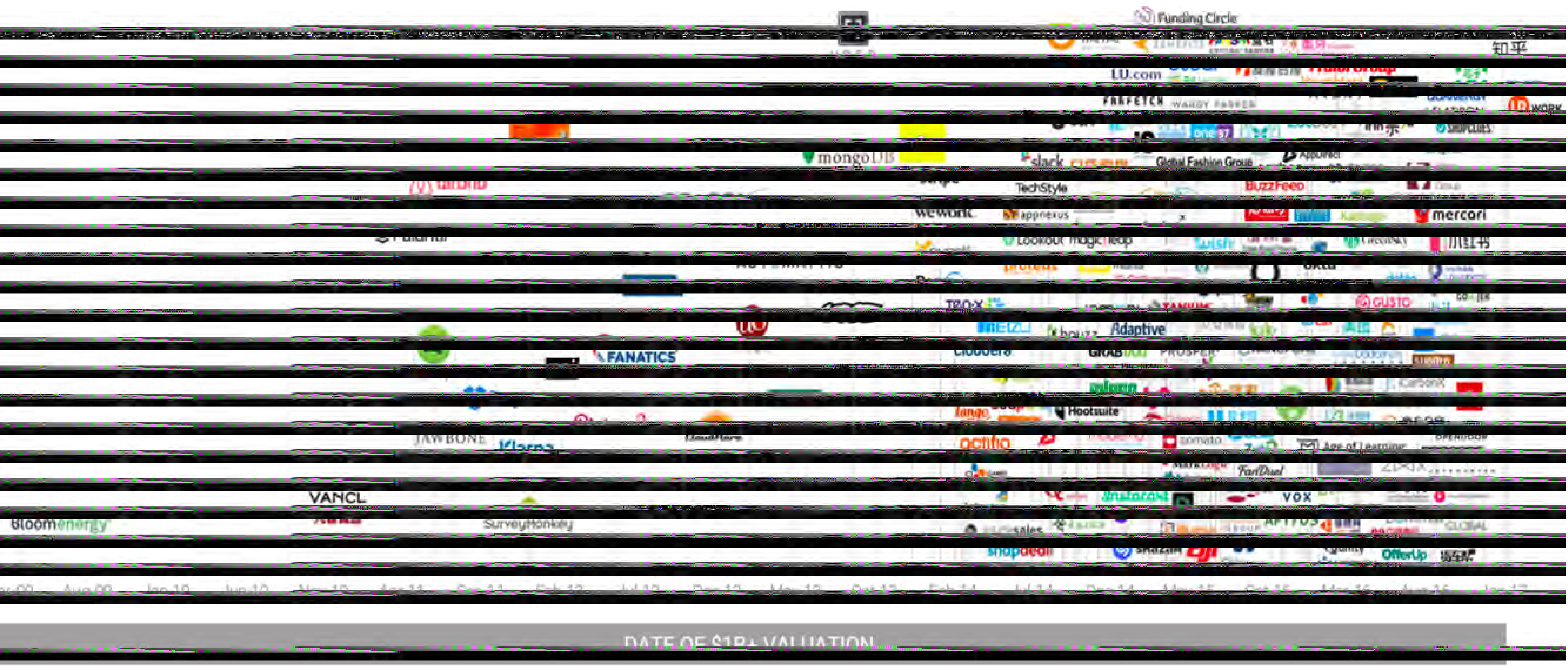
Research Fellow at Research Technology and Innovation Network (RTIN)

kvoutsina@acg.edu

The brave new world of Startups….

THE INCREASINGLY CROWDED UNICORN CLUB: PRIVATE COMPANIES VALUED AT $1B+

as of 1/31/2017



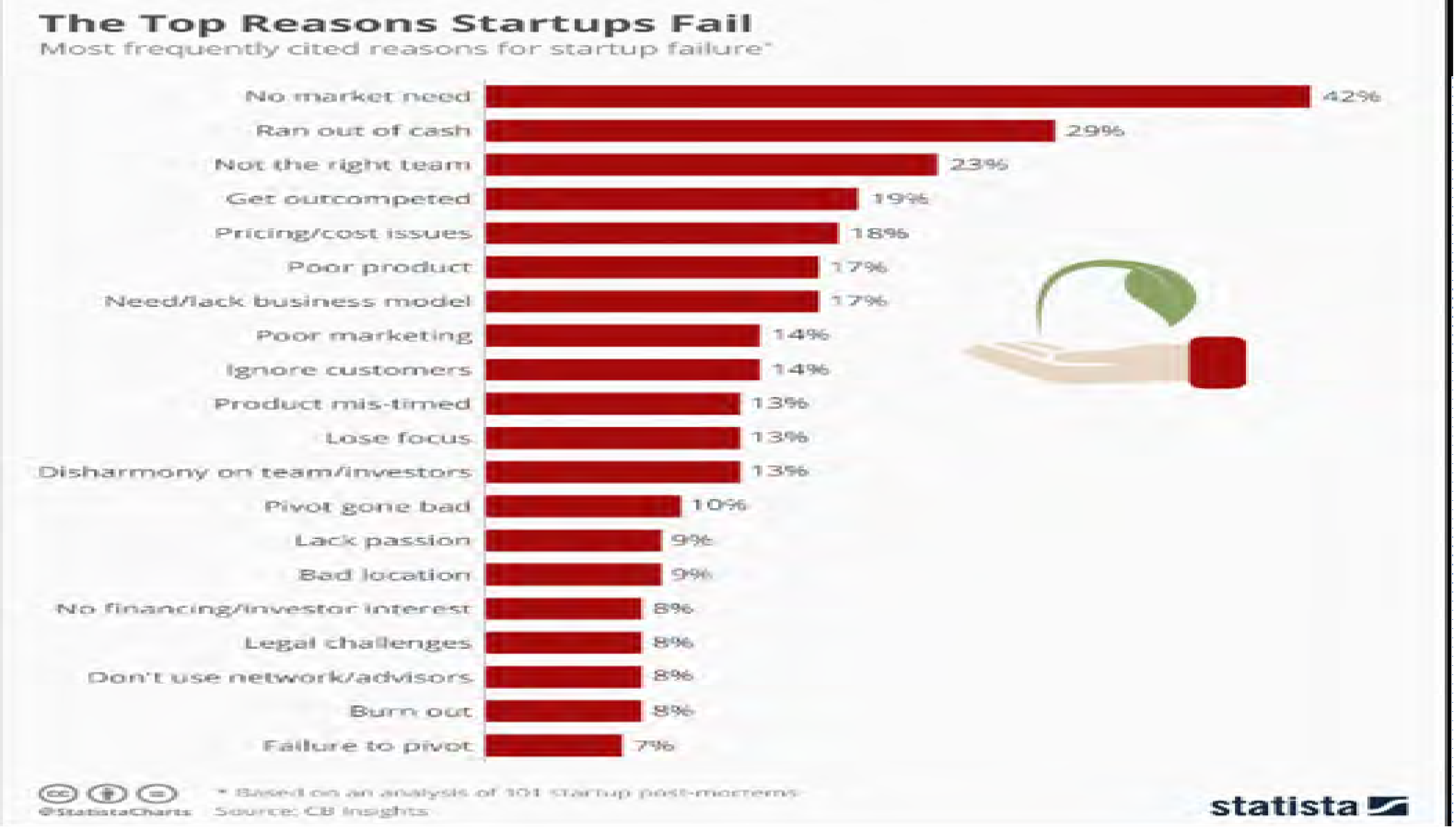
CB INSIGHTS

Some facts…

The Startup Genome* 2019 Report investigated over 3,200 *high growth Tech Startups.*

The findings revealed that **over 90% fail**, in most cases due to *self-destruction* rather than competition.

(*): Startup Genome is a world-leading innovation policy advisory and research firm, having advised the ecosystem development strategy and action plans for more than 45 governments in the last year.


The Top Reasons Startups Fail
Most frequently cited reasons for startup failure*
No market need 42%
Ran out of cash 29%
Not the right team 23%
Get outcompeted 19%
Pricing/cost issues 18%
Poor product 17%
Need/lack business model 17%
Poor marketing 14%
Ignore customers 14%
Product mis-timed 13%
Lose focus 13%
Disharmony on team/investors 13%
Pivot gone bad 10%
Lack passion 9%
Bad location 9%
No financing/investor interest 8%
Legal challenges 8%
Don't use network/advisors 8%
Burn out 8%
Failure to pivot 7%
@StatistaCharts
* Based on an analysis of 101 startup post-mortems
Source: CB Insights
statista

What is actually a Startup ?

Popular definition of a startup:

- a “*tech company with less than 100 people*”

Old-formula:

- you write a business plan
- pitch it to investors
- assemble a team
- introduce a product
- start selling as hard as you can.

A new understanding of a Startup

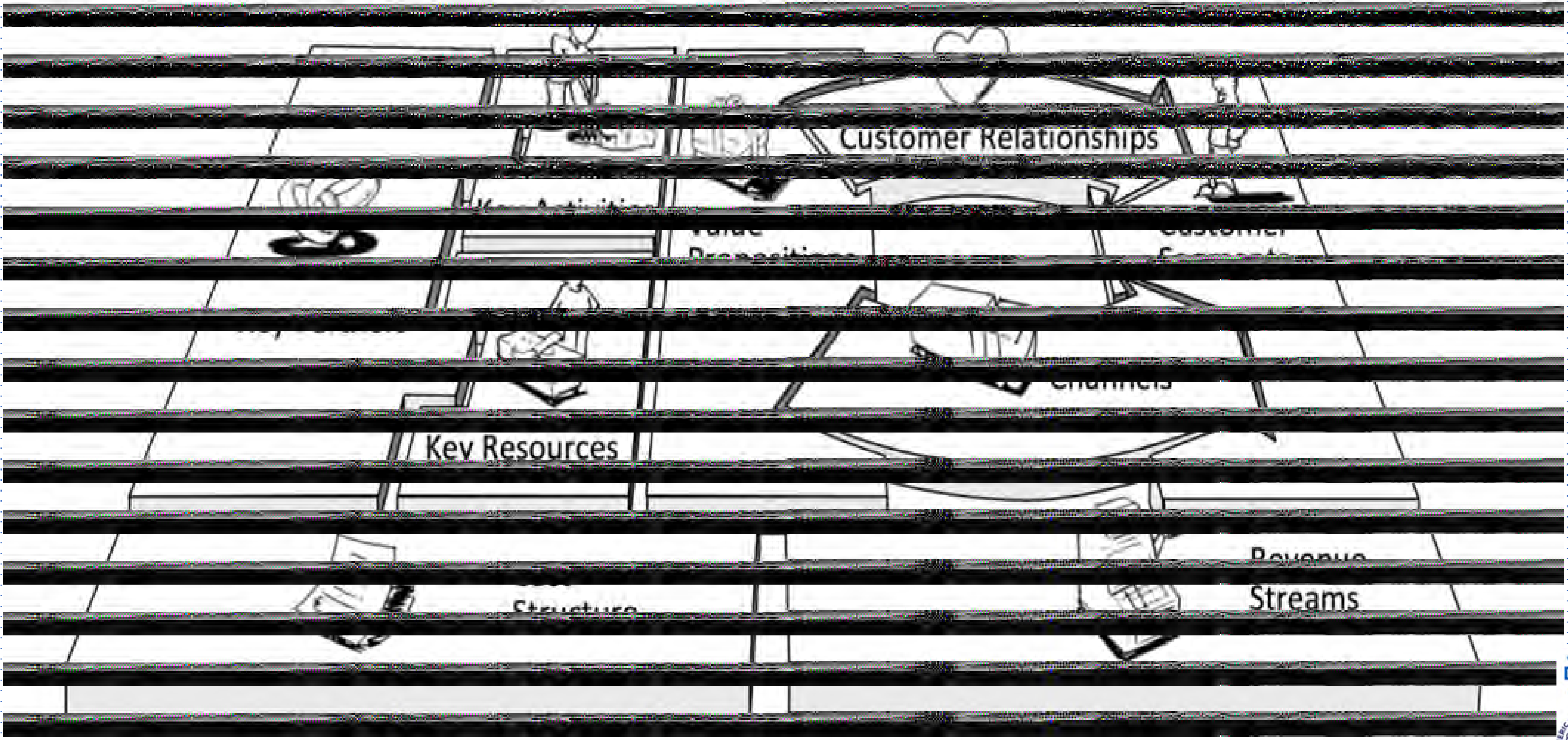
- ✓A startup is a "*temporary organization designed to* ***search*** *for a repeatable and scalable business model*", while the small business existing companies *execute* a rather fixed business model (Steve Blank- *The 4 stages of epiphany*).

- ✓A start-up is a "*human institution designed to create a* ***new*** *product or service under conditions of* ***extreme uncertainty***" (Eric Ries- *Lean Startup*)

- ✓*A startup is a "company working to solve a problem where* ***the solution is not obvious and success is not guaranteed.***" *(*Neil Blumenthal, co-founder & co-CEO of *Warby Parker)*

Business model

The Business Model Canvas (Alexander Osterwalder)



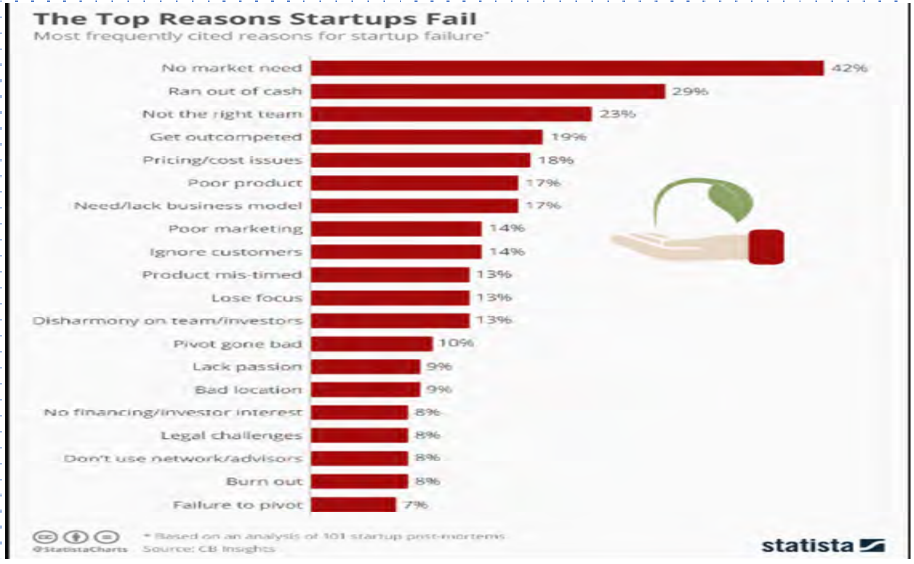
The underlying problem of Startups

Be reminded: A start up is

- a "*temporary organization designed to* ***s e a r c h*** *for a repeatable and scalable business model*", while the small business existing companies ***e x e c u t e*** a rather **fixed** business model

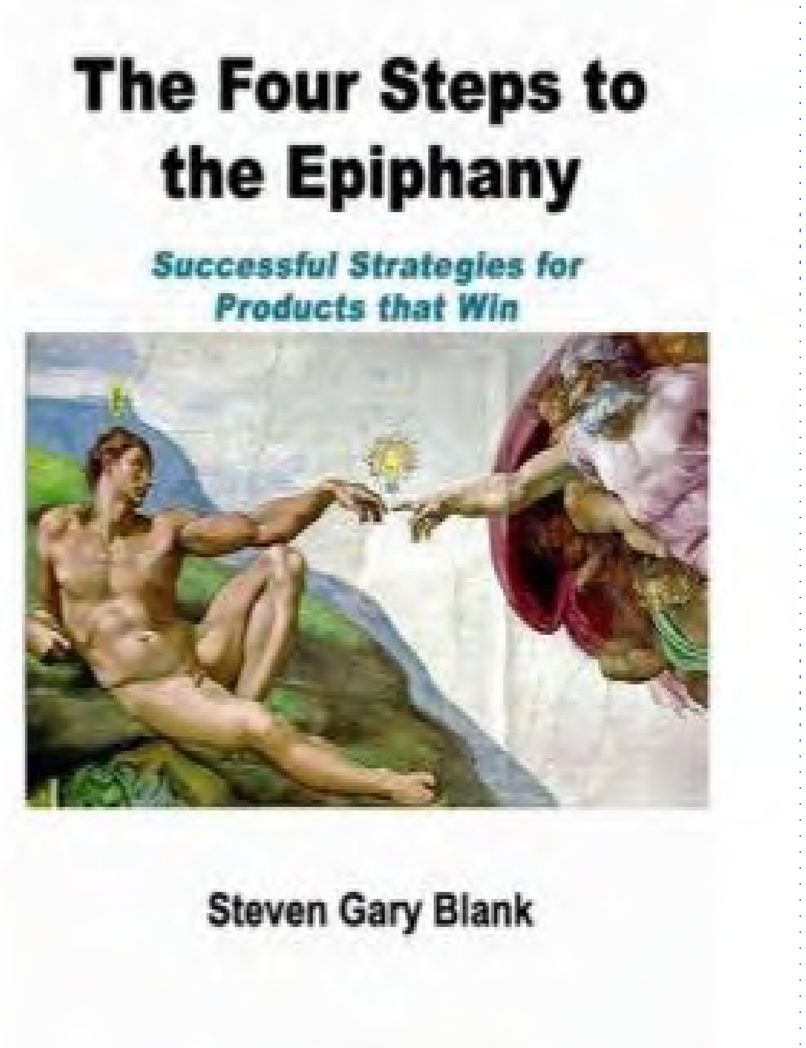
- a human institution designed to create a new product or service *under conditions of extreme uncertainty*

- *a company working to solve a problem where the solution is not obvious and success is not guaranteed."*



ACG 150
Futureproof Greece

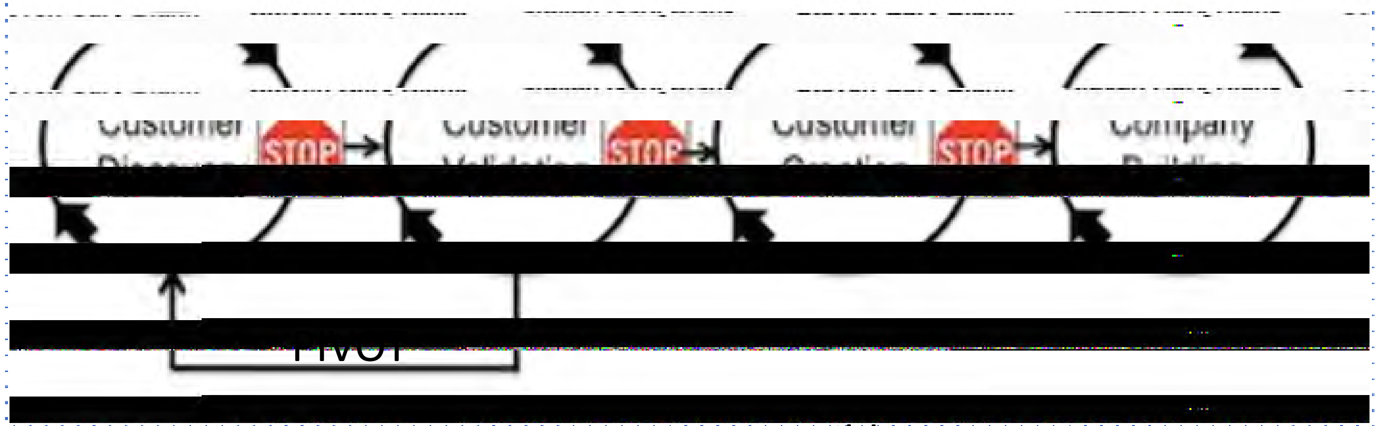
A possible remedy for Startups



Identify problem & BM

Build MVP & validate BM

Execution



[redacted]

Problem-Solution Fit
-Develop the Business Model

Product-Market Fit
-Develop MVP
-Sell to early adopters/ Earlyvangelists

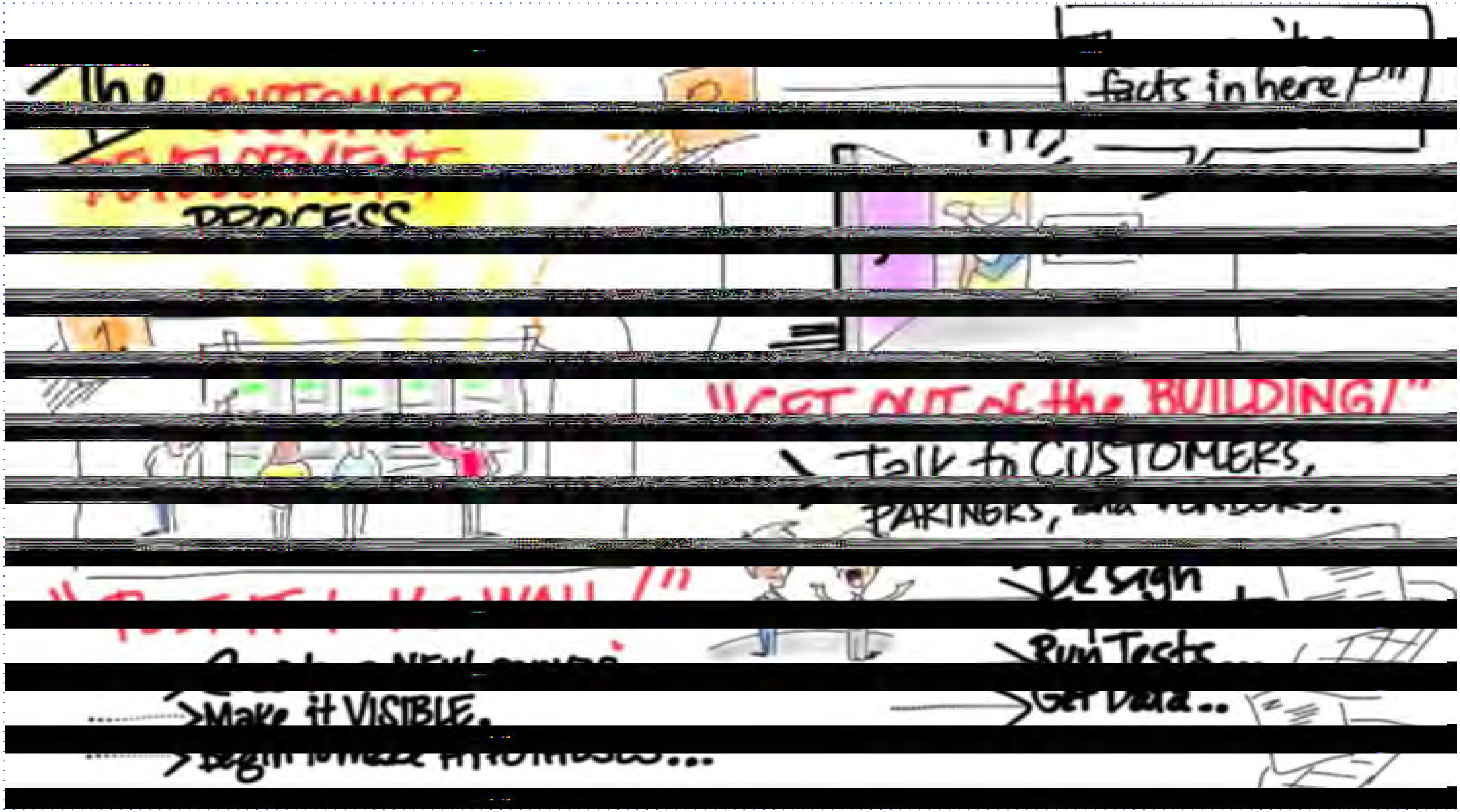
Build demand – Mrk roadmap & launch strategy

-Sell to mainstream customers
-Develop a functional org. structure

Small-funding team
Startup

Scale the team
Formal Organization

Deree


PROCESS
facts in here
"GET OUT of the BUILDING!"
Talk to CUSTOMERS,
Design
Run Tests
Get Data..
Make it VISIBLE,

Business model validation & Lean methodology

Build a venture step by step – by an iterative process of explicitly formulating and testing ALL assumptions

- ✓Summarize the assumptions via the BMC
- ✓Get outside the building to test those assumptions with MVP: take feedback on all elements of the business model
- ✓Drawing on customers' feedback revise your assumptions customers and start the cycle over again making smaller adjustments (iterations) or more substantial ones (pivot)
- ✓Agile development: start-ups create the MVPs they test-> Customer Development// Product Development

The promise of Minimum Viable Product (MVP)
'Develop products that resonate with customers'

The Minimum Viable Product:

"is that version of a new product a team uses to collect the maximum amount of validated learning about customers with the least effort." (Eric Ries)

- ✓ It is more than a prototype with just the set of features required to gather *validated learnings* about it or some of its features
- ✓ It is rather a process *(experimentation and iteration)* of investing the smallest amount of effort to learn.

"YOU WILL GET ALL YOU WANT IN LIFE, IF YOU HELP ENOUGH OTHER PEOPLE GET WHAT THEY WANT"

Zig Ziglar

Venture Capital:
An Insider's View for Entrepreneurs and Researchers

Alex Eleftheriadis, Ph.D.
Partner, Big Pi Ventures
&
Chief Scientist, Enghouse

http://linkedin.com/in/eleft

May 10, 2022

Some History

- Silicon Valley


WASHINGTON
MONTANA
NORTH DAKOTA
OREGON
IDAHO
WYOMING
NEVADA
UTAH
San Francisco
CALIFORNIA
Las Vegas
Los Angeles
ARIZONA
San Diego
Gulf of California
Mexico
Ottawa
Montreal
MAINE
VT
NH
NEW YORK
MA
CT
RI
PENN
Philadelphia
MD
DE
NJ
San Francisco
Oakland
Alameda
Tassajara
San Ramon
San Leandro
Dublin
Daly City
South San Francisco
San Bruno
Hayward
Pleasanton
Pacifica
Union City
Sunol
San Mateo
Fremont
Bair Island
Don Edwards San Francisco Bay National Wildlife...
El Granada
Redwood City
Half Moon Bay
Palo Alto
Milpitas
Mountain View
Lobitos
San Jose
San Gregorio
La Honda
Cupertino
Campbell
Saratoga
Pescadero
Los Gatos
1
280
101
880
580
680
92
35
82
238
84
237
85
87
17
9

Some History

- Silicon Valley
- Fred Terman, Stanford EE Professor/Dean
- Hewlett Packard founded in 1939
- Terman brought Shockley in 1956 (co-inventor of transistor)
  - 8 Shockley employees started Fairchild Semiconductor in 1957
  - 38 companies started from Fairchild employees
  - Intel among them (Gordon Moore & Robert Noyce, 1968)
    - $77.8B revenue (2020), 110,600 employees

What is Venture Capital?

Equity for startups

not grant, not loan

Innovation

business model or technology

High risk, high return

Grow and exit

Venture Startup Company Stages

- Founding Team Formation & Concept
- Self-funded or Angel Investors provide Seed Capital (~100-300K)
  - Use of convertible loans or SAFE (Simple Agreement for Future Equity) with discounts/caps to avoid valuation
- Series A Investment Round (first "Institutional Investors") (~1-5M)
- Series B, C, etc. Investment Rounds (existing investors may participate) (>10M)
- Sale or Initial Public Offering (IPO, >100M), ideally in <6 years

Value Creation & Cap Table Example

Series A Cap Table						
	Common Stock		Series A Preferred Stock			
NAME	Outstanding	Capital	Outstanding	Investment Amount	Total Fully Diluted	Fully Diluted % Ownership
John Smith	45,000	500			45,000	36.00%
Mary Jones	45,000	500			45,000	36.00%
Happy Investing Fund IV, LLC			25,000	$ 1,000,000	25,000	20.00%
Shares Allocated to Incentive Plan	10,000				10,000	8.00%
TOTAL	**100,000**	**1,000**	**25,000**	**$ 1,000,000**	**125,000**	**100.00%**
Pre-money Valuation		$ -		$ 4,000,000		
Post-money Valuation		$ 1,000		$ 5,000,000		
Share Price		$ 0.01		$ 40.00		

Post-investment, John is worth 36% x 5,000,000 or 1,800,000!

Two Exit Scenaria

- Company is sold in 5 years at 50M
  - VC's 20% is 10M (IRR 58%)

- Company IPOs in 5 years, offers 10% for 50M (500M valuation)
  - VC 20% will dilute to 18.18% but most of it will be sold at IPO – total value 90.9M (IRR 146%)
  - Founders are each "worth" 163M!
    - Will be allowed to sell only portion of their stock

Two Bad Scenaria

- Down round
  - Valuation lower than previous round (dilution without value appreciation)

- Liquidation
  - Institutional investors have priority (“liquidation preference”), paid back capital plus interest, typically after any loans are paid

Stock Options for Employees

- 10-15% of total equity allocated to stock options for employees
- Stock option package for an employee with Board approval with a set number of shares and given per-share price
- 4-year vesting schedule with one-year cliff for new employees (each month locks 1/48 of the package)
  - Vesting automatic upon liquidation event (sale or IPO)
  - You buy the stock and sell it the same day and also cover tax due from the proceeds
  - Note: 3-6 month lock-up typical after an IPO for options holders!
- Options typically expire in 10 years (must decide if you will buy)

Venture Capital Firm Entities & Terms

- Partners
- Associates
- Limited Partners (partners are usually also LPs)
- Capital under management
- Capital Call
- Investment Period
- Lead investor
- Follow-on investment
- Pro-rata / drag-along / tag-along

How do VCs Make Money?

- Management Fees
- Carried Interest
  - Partners get X% of capital gains achieved beyond a minimum annual return for LPs, e.g., 6% per annum
- KPIs: multiples, IRR, etc.
- Multiple funds under management (Happy Investing Fund I, Happy Investing Fund II, etc.) in a pipeline mode

What value do VCs bring?

- Capital
- Management Experience (indirectly and via seat on Board of Directors)
- Business development connections
  - Suppliers
  - Contractors
  - Customers
- Access to follow-on capital (other VCs, venture lending)
- Prep for IPO, acquisition negotiations

Greek Ecosystem

Research

- Good basic research
- Little commercial application
- Contracts, not products

Startups

- 100s since 2013
- Business innovation, light tech
- Almost no spinoffs

Funds

- Comparatively underfunded
- JEREMIE funds 2012-2016
- “EquiFund” 2018-2023 equifund.gr

“Innovation Window”

BIG PI

uni.fund
MAKE IT HAPPEN

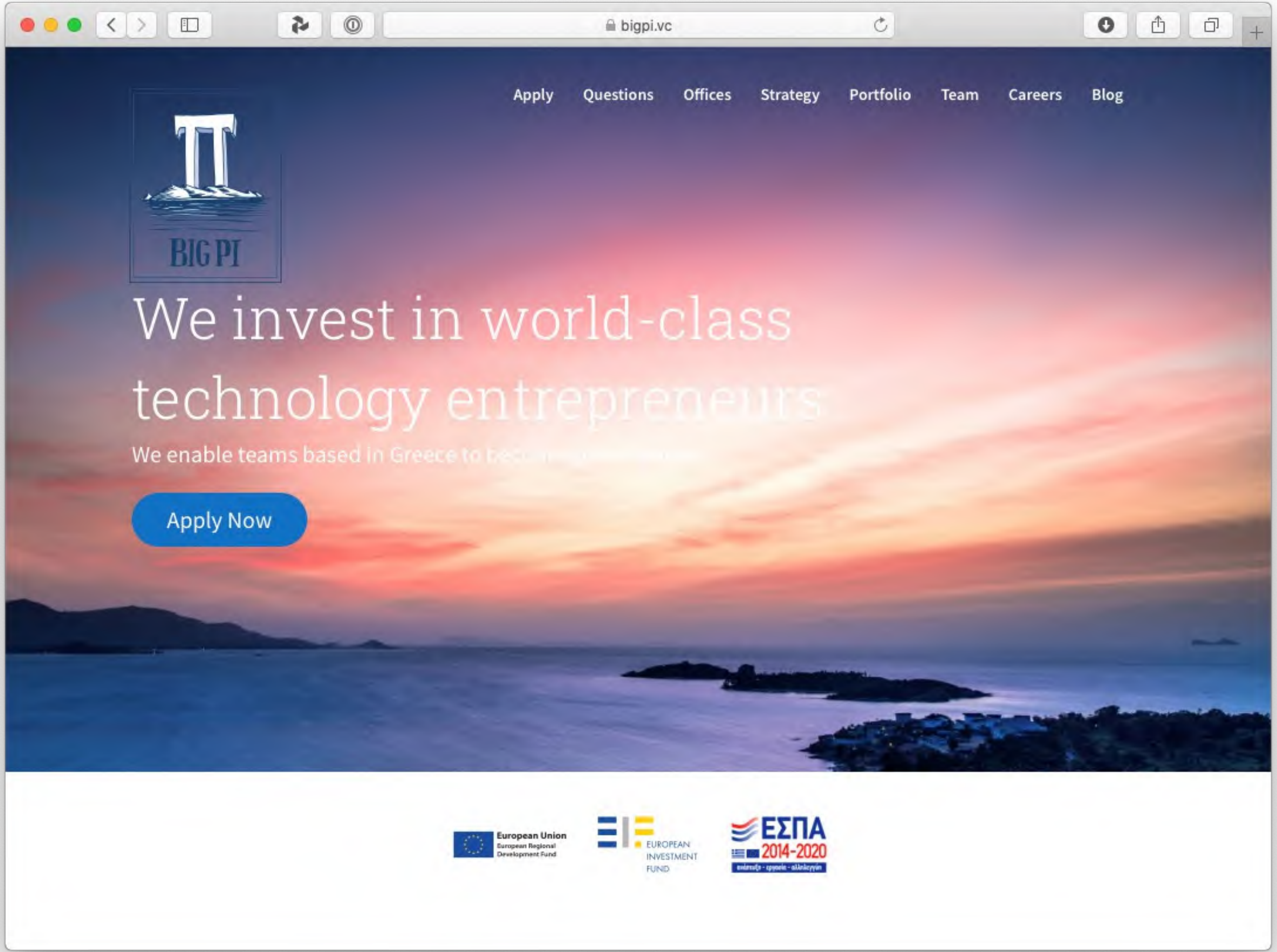
METAVALLON

VELOCITY
PARTNERS

“Early Stage”

VentureFriends

MARATHON
VENTURE CAPITAL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We invest in world-class technology entrepreneurs
We enable teams based in Greece to
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European Regional Development Fund
EUROPEAN INVESTMENT FUND
ΕΣΠΑ
2014-2020

Big Pi

- Founding Partners: Doxiadis, Eleftheriadis, Veremis
- Deep tech, early stage fund (Seed/Series A)
- 45M Euro capital
- 23 investments
    - 7 - Greek research institutions
    - 11 - Founders based abroad
    - 5 - Other
- Big Pi II in the works
    - 60-80M EUR capital
    - Support from HDBI's InnovateNow

Big Pi investment strategy

Stages

Lead the seed stage

€200K-1.5M

Follow in Series A

Up to €3.5m

(Total: up to €5.0m)

Sectors

- Software/ Data/ AI
- Hardware
- Materials
- Chemical engineering
- Life sciences

Targets

- 20-25 portfolio companies
- At least 50% with science-based IP
- Successful exit valuations at €50M - €300M

Product Math

dV: increase in value $\qquad$ dC: increase in cost

	$dV > 0$	$dV < 0$
$dC > 0$	$dV/dC > 0$	~~$dV/dC < 0$~~
$dC < 0$	$dV/dC < 0$	$dV/dC > 0$

Extra features for extra cost (or new product category)

Extra features for lower cost

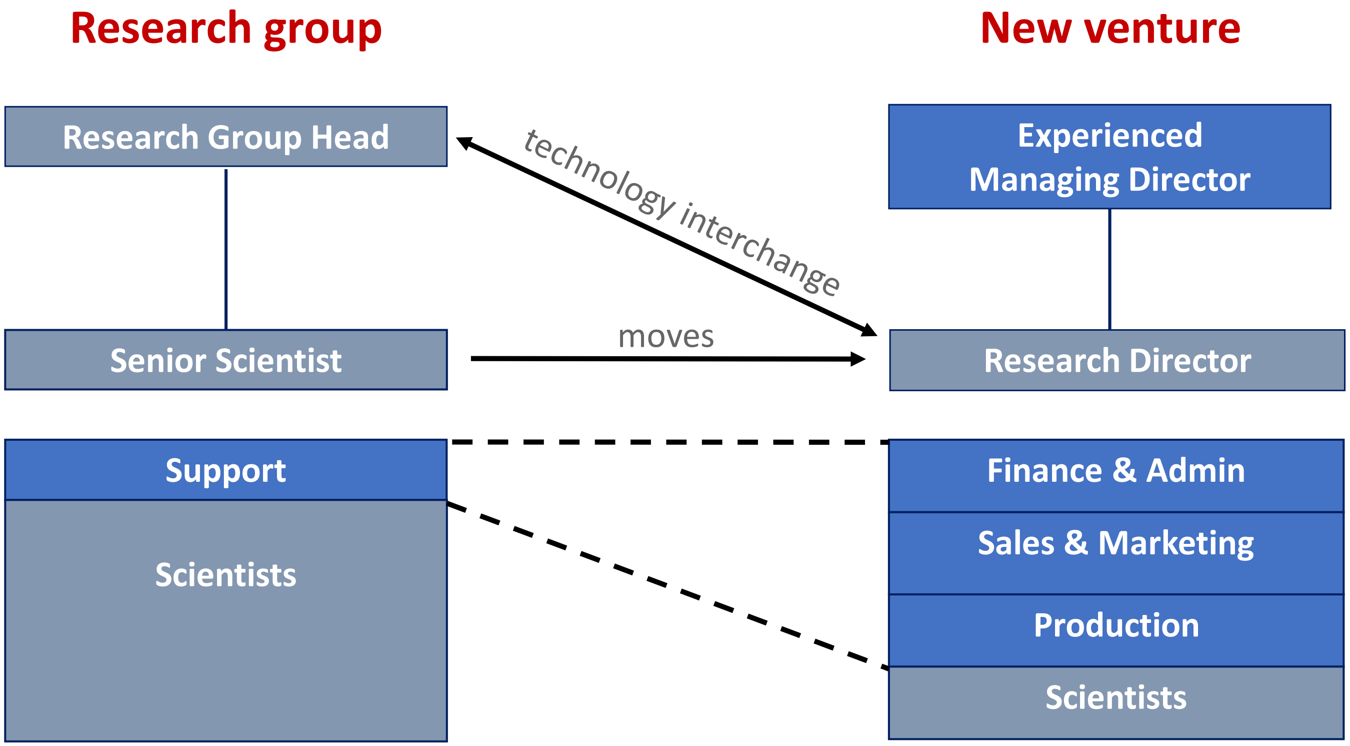
Lower features for lower cost (e.g., 3/4 features for 1/100 cost)

Investment Criteria

When looking at proposals, we make an assessment based on:

- **T**eam
- **T**AM (Total addressable market)
- **T**ech (Product quality)
- **T**renches (Defense against competition)
- **T**raction (Adoption by users; sales)
- **T**imeline (Roadmap)

People Changes in Creating a New Venture



Source: University of Oxford, Said Business School

Portfolio

prosperty
ALTERED
SAPHETOR
Biomimetic.
ORFIUM
ANODYNE Nanotech
dataviva
Bryq
pd neurotechnology medical solutions
navenio
PCNano materials
ATHROA INNOVATIONS
vivante HEALTH
2bull
accusonus
Phenometry
Kinems LEARNING GAMES
SpaceTalos
intelligencia.ai
[tile]DB
balena
Fieldscale

•Intellectual Property

Patents

- exclusive commercial right for 20 years in exchange for public disclosure
- offensive, defensive, royalties, collateral or exit asset
- file in the US, EPO, Greece

Caveats

✓first-to-file, no early disclosure (US only, 12m)
✓invalid if you miss an inventor
✓clarity on assignee (owner of rights)

Intellectual Property

Copyrights

- protects rights of authors (life+70y)
- applies to software
- exists the moment it is fixed in tangible form
- assigned to employers through agreements

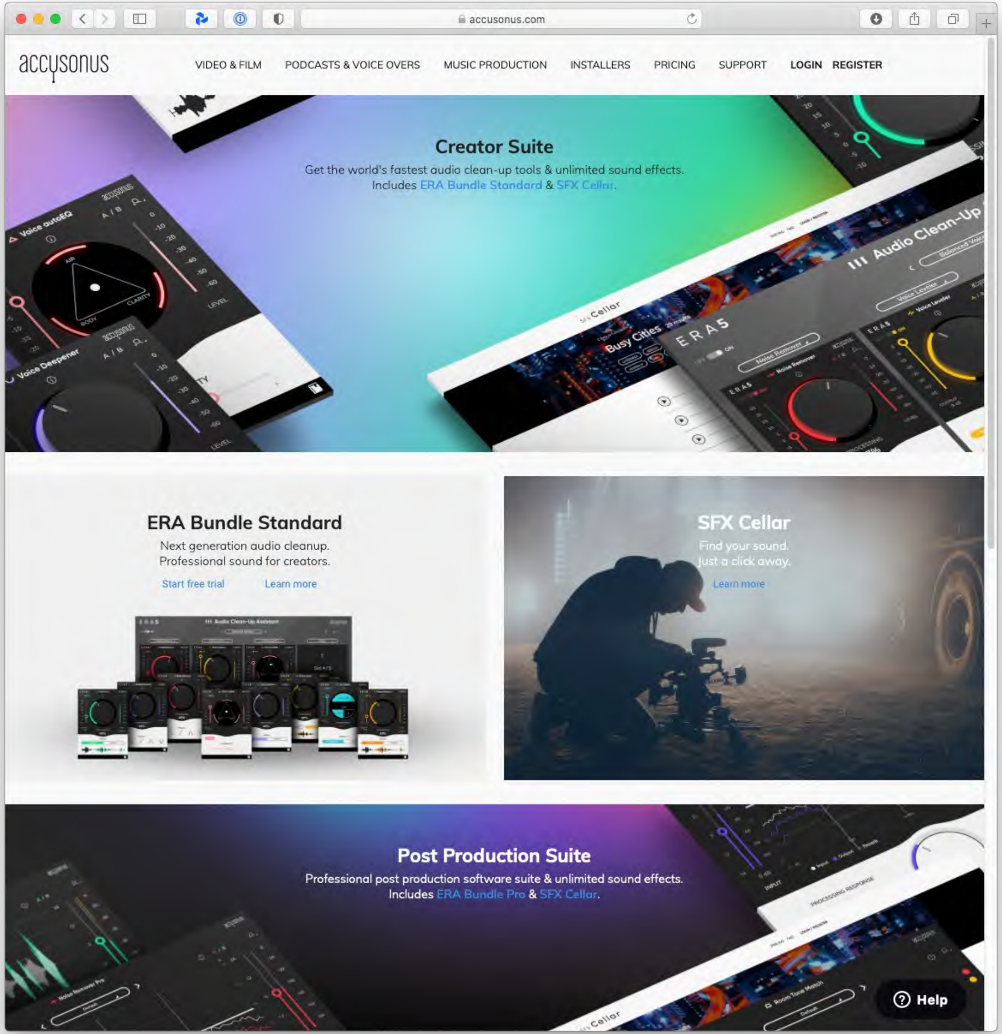
Caveats

- ✓developers who have not assigned their copyright
- ✓viral (copyleft) open source licenses

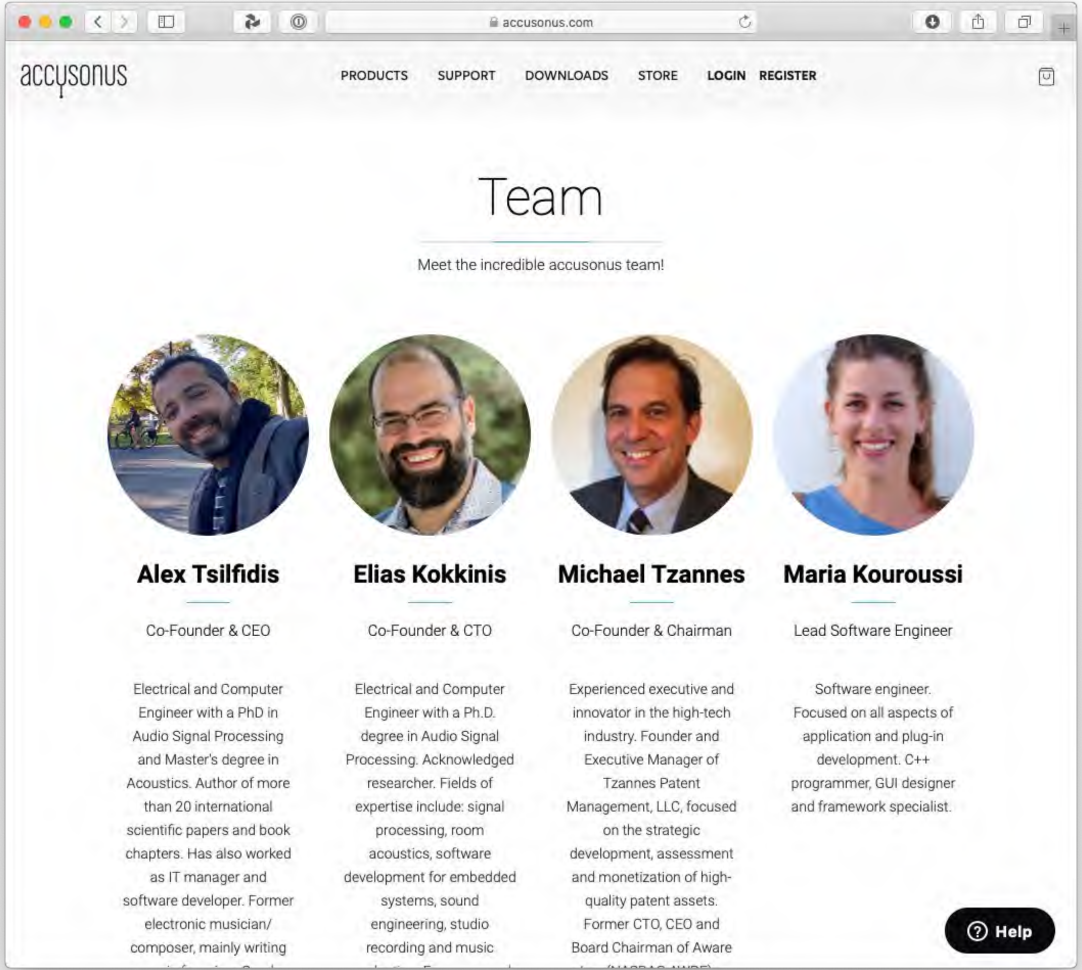
The Mechanics

- Pitch deck
  - 10-20 slides addressing all aspects of the business
  - Includes summary financials
  - Investment ask and what stage will it get you to
- After a successful first meeting
  - Detailed Excel business model (quarterly granularity)
  - Detailed use of funds Excel (quarterly or monthly granularity)
- One or more iterations
  - Technical, business, legal due diligence as needed (possibly including outside advisors)
- If VC investment committee agrees to invest
  - Term sheet will be offered outlining business terms (funding amount, valuation, other)
  - Upon acceptance, the company's lawyers will convert the term sheet to a definitive investment agreement
  - One partner will become Board member
- This is just the beginning of the company's journey

Case Study: Accusonus



Case Study: Accusonus



Case Study: Accusonus

Η Facebook εξαγοράζει την ελληνική startup Accusonus

Ο αμερικανικός κολοσσός σχεδιάζει να ιδρύσει και θυγατρική στη χώρα μας

Του ΗΛΙΑ Γ. ΜΠΕΛΛΟΥ

Σε προχωρημένες συζητήσεις για την ίδρυση ελληνικής θυγατρικής εταιρείας, κάτω από την ομπρέλα της οποίας θα μπορούν να μεταφερθούν προοπτικά διεθνείς δραστηριότητες που αυτή τη στιγμή υλοποιούνται από άλλες χώρες, αλλά και για την εξαγορά της ελληνικής εταιρείας προηγμένης ηχητικής τεχνολογίας Accusonus, βρίσκεται η μητρική εταιρεία του Facebook, Meta Platforms, Inc.

Σύμφωνα με πληροφορίες, η Meta Platforms θα εξαγοράσει το 100% της Accusonus από τους ιδρυτές και μετόχους της, Αλέξανδρο Τσιλφίδη, Ηλία Κοκκίνη και Μιχάλη Τζάννε, όπως και έτερο μέτοχό της, το κεφάλαιο επιχειρηματικών συμμετοχών Big Pi Ventures, συμφερόντων Μάρκου Βερέμη, σε αποτίμηση (enterprise value) που κινείται στην περιοχή μεταξύ 70 και 100 εκατομμυρίων ευρώ. Οι υπογραφές έχει προγραμματιστεί να μπουν, εκτός απροόπτου, την ερχόμενη Παρασκευή και οι σχετικές ανακοινώσεις να γίνουν στις αρχές της επόμενης εβδομάδας.

Η Meta Platforms, που πραγματοποιεί τις σχετικές διαπραγματεύσεις εδώ και λίγους μήνες, όχι μόνο θα διατηρήσει τη δραστηριότητα της Accusonus στην Ελλάδα, και ειδικότερα στην Αθήνα και στην Πάτρα όπου διατηρεί γραφεία (αλλά έχει έδρα στη Μασαχουσέτη των ΗΠΑ), αλλά και θα επενδύσει για να την αναπτύξει περαιτέρω. Στόχος της είναι η ελληνική startup να παρέχει τις λύσεις ήχου που απαιτεί ο κόσμος εικονικής πραγματικότητας ή metaverse που αναπτύσσει ο αμερικανικός τεχνολογικός κολοσσός. Σημειώνεται πως ο όρος «metaverse» περιγράφει τη σύζευξη της πραγματικότητας και της εικονικής πραγματικότητας με αποτέλεσμα την επαυξημένη πραγματικότητα στο πλαίσιο των κοινωνικών δικτύων. Με αυτό τον τρόπο μία ελληνική εταιρεία θα «τρέχει» ένα σημαντικό κομμάτι της παγκόσμιας ραχοκοκαλιάς του metaverse.

Ο ιδρυτής του Facebook, Μαρκ Ζούκερμπεργκ, βρίσκεται ένα βήμα πριν ανοίξει τη Meta Hellas, θυγατρική με ελληνικό ΑΦΜ που μελλοντικά μπορεί να απασχολήσει αρκετές εκατοντάδες εργαζομένους από τους 68.177 ανθρώπους που εργάζονται για αυτήν παγκοσμίως.

Οι υπογραφές για το ντιλ αναμένεται να πέσουν την ερχόμενη Παρασκευή.

Παράλληλα, ήδη από τον Σεπτέμβριο στελέχη της Meta Platforms ήρθαν σε επαφή με την ελληνική κυβέρνηση προκειμένου να αξιολογήσουν την προοπτική να ιδρύσουν εδώ θυγατρική και να μεταφέρουν σημαντικότατο αριθμό εργαζομένων τους από άλλες επικράτειες στην Ελλάδα. Τις σχετικές συζητήσεις και τα ερωτήματα που είχε η ομάδα της αμερικανικής εταιρείας ανέλαβε να συντονίσει και να απαντήσει επιτελείο της κυβέρνησης υπό τη διεύθυνση του επικεφαλής του οικονομικού γραφείου του πρωθυπουργού Κυριάκου Μητσοτάκη, Αλέξη Πατέλη.

Οι συζητήσεις περιλάμβαναν αναλυτικές παρουσιάσεις τόσο του φορολογικού και εργατικού πλαισίου στην Ελλάδα όσο και της ασφαλιστικής κάλυψης και των παροχών και κινήτρων που έχουν ήδη νομοθετηθεί για να προσελκύσουν αλλοδαπούς εργαζομένους και εταιρείες να μετεγκατασταθούν και να εργάζονται από εδώ.

Καθοριστικό ρόλο στις αποφάσεις της Meta Platforms διαδραμάτισε βεβαίως το γεγονός ότι η Ελλάδα κατάφερε την τελευταία διετία να προσελκύσει επενδύσεις από τεχνολογικούς κολοσσούς, όπως η Microsoft, η Amazon Web Services και η Digital Realty, που εξαγόρασε την ελληνική Lamda Helix, οι οποίες αναπτύσσουν data centers και υπηρεσίες cloud τελευταίας γενιάς στη χώρα μας, παρέχοντας την απαραίτητη υποδομή για να φιλοξενηθούν τμήματα της δραστηριότητας της μητρικής εταιρείας του Facebook.

Και κάπως έτσι η Meta, η χρηματιστηριακή αξία της οποίας τη Δευτέρα το απόγευμα στο χρηματιστήριο της Νέας Υόρκης ήταν στα 853 δισεκατομμύρια δολάρια, βρίσκεται ένα βήμα πριν ανοίξει τη Meta Hellas, θυγατρική με ελληνικό ΑΦΜ που προοπτικά μπορεί να απασχολήσει αρκετές εκατοντάδες εργαζομένους από τους 68.177 ανθρώπους που εργάζονται για αυτήν παγκοσμίως.

Αναπτύσσει λογισμικό τεχνητής νοημοσύνης για την επεξεργασία ήχου

Τα προϊόντα της ελληνικής Accusonus, startup η οποία ιδρύθηκε το 2013, χρησιμοποιούνται από πολλούς βραβευμένους με Grammy παραγωγούς που έχουν συνεργαστεί με ηχηρά ονόματα της μουσικής βιομηχανίας, όπως οι Μπομπ Ντίλαν, Λου Ριντ, Σακίρα και πολλοί ακόμα. Πρόκειται για εταιρεία που αναπτύσσει εργαλεία τεχνητής νοημοσύνης, τα οποία βοηθούν στην επεξεργασία ήχου και βίντεο. Επαγγελματίες και μη έχουν τη δυνατότητα μέσω των αλγορίθμων της να επιδιορθώνουν άμεσα τον ήχο στα βίντεό τους, δίνοντας μάλιστα την εντύπωση πως έχουν γυριστεί εντός ενός επαγγελματικού στούντιο.

Η Accusonus απασχολεί πάνω από 50 άτομα και σύμφωνα με στοιχεία του Crunchbase, μέχρι πρόσφατως είχε συγκεντρώσει 3,9 εκατ. δολάρια από την αγορά, γνωστοποιώντας το 2019 ότι εξασφάλισε επένδυση ύψους 3,3 εκατ. δολ. (Series A). Στον γύρο εκείνο ηγήθηκε το ελληνικό Venture Friends και συμμετείχαν το επίσης ελληνικό Big Pi Ventures, το IQBility του ομίλου Quest, η PJ Tech Catalyst της Τράπεζας Πειραιώς, αλλά και μια ομάδα Αμερικανών επενδυτών υπό τον Michael Tzannes, συνιδρυτή της accusonus και πρώην CEO της εταιρείας Aware, η οποία πρωτοστάτησε στην ανάπτυξη της τεχνολογίας DSL.

Είναι από τις πρώτες εταιρείες που ανέπτυξαν προϊόντα μηχανικής μάθησης στην αγορά λογισμικού επεξεργασίας ήχου, λανσάροντας το 2014 το προϊόν Drumatom. Όπως είχε εξηγήσει σε παλαιότερη συνέντευξή του στην «Κ» ο κ. Τσιλφίδης, το συγκεκριμένο εργαλείο είναι το πρώτο της εταιρείας και βοηθάει τους επαγγελματίες ηχολήπτες να βελτιώσουν τον ήχο των ηχογραφήσεων τυμπάνων. Λίγα χρόνια αργότερα, το 2017, η ομάδα λάνσαρε το Regroover, ένα λογισμικό τεχνητής νοημοσύνης που μπορεί να αναλύσει ένα μιξαρισμένο ηχητικό δείγμα και να το χωρίσει στις αρχικές πηγές από τις οποίες προήλθε. Άλλα προϊόντα είναι το ERA Bundle, SFX Cellar κ.ά. Σημαντικός σταθμός στην πορεία της εταιρείας ήταν η ανακοίνωση της συνεργασίας της με την Adobe το 2018, στο πλαίσιο της οποίας η πατενταρισμένη τεχνολογία της νεοφυούς εταιρείας ενσωματώθηκε στα προγράμματα της Adobe για την παραγωγή οπτικοακουστικού περιεχομένου.

Τα προϊόντα της χρησιμοποιούνται από πολλούς βραβευμένους με Grammy παραγωγούς.

ΔΕΣΠΟΙΝΑ ΚΟΝΤΗ

Η Accusonus ιδρύθηκε το 2013 και απασχολεί πάνω από 50 άτομα.

Στο στόχαστρο ξένων ομίλων έχουν μπει ελληνικές επιχειρήσεις

Του ΔΗΜΗΤΡΗ ΔΕΛΕΒΕΓΚΟΥ

Σε επενδυτικό μαγνήτη τείνουν να μετατραπούν οι ελληνικές εταιρείες, οι οποίες, ολοένα και

Ποιες μεγάλες συμφωνίες έχουν πραγματοποιηθεί

τον έλεγχο και τεσσάρων εταιρειών του ομίλου Μουχάλη (5), ενώ, πριν από χρόνια, ενέταξε στην ομπρέλα της την ηλεκτρονική πλατφόρμα e-food. Με τις εξαγο-

από τον όμιλο που ανήκει στην BC Partners.

Τρόφιμα

Επίσης, ο κλάδος των τροφί-

Kathimerini
February 1, 2022

BIG PI

Alex Eleftheriadis, Ph.D.
alex@bigpi.vc

http://linkedin.com/in/eleft

Backup Slides

6 T's: Team

- What skills are present?
- Complementary?
- How many people are full-time?
- Founder experience?
- Experience in the field?
- Team dynamics

6 T's: TAM: Total Addressable Market

- How big?
- One vertical or many?
- Barriers to expanding (logistics; local differences; regulation)

6 T's: Tech

- Does the technology actually work?
- Does it address a real problem for a specific kind of user?
- What is the advantage: cost/ speed/ ease/ what else?
- Is the product complete (MVP)?
- The tech expertise must be integral part of the team and not outsourced

6 T’s: Trenches

Patents / Trade secrets / Unique know-how

- Patents are a strong asset -> File them on time!
- Budget for IP
- Who owns the IP? Are you free to use it?
- Geographical choices to be made soon after filing
- Secret sauce to build your product -> do not disclose

6 T’s: Traction

- If you have regular sales:
  - How fast are they growing?
  - Are users satisfied/ recurring/ recommending?
- If no sales yet:
  - What interactions have you had with potential users?

Get early traction; don’t wait for the perfect product (the MVP concept)

6 T’s: Timeline

- Does the team have a timeline on paper?
- Is it detailed enough to show milestones you can monitor?
- Is the investment ask adequate to provide enough “runway”?

Don’t plan milestones only at the end of the runway.

Runway is typically 18M with MVP milestone at 12M the latest.

"Your first institutional investment: how it works and why it is important?"

Stergios Anastasiadis, General Partner at Genesis Ventures
PAINLESS 4th Summer School
@ The American College of Greece
May 2022

BEFORE IT ALL STARTS

Launch the product right away

Startup founders

“This is the only way to fully understand customers’ problems

“And whether the product meets their needs

Founder blueprint is validated

Startup founders

This is the secret sauce to nailing an early investment

Solving real and difficult problems

Raise money as quickly as possible

Startup founders

> Then get back to work building product and growing

> Easy to actually see when a company is fundraising by looking at their growth curve and when it flattens out you know they are raising money

HOW IT WORKS

Structure, Source, Price

Founders
and
Investors

Rounds: credit cards, friends & family [debt], pre-Seed & Seed [convertible], Series+ [equity]

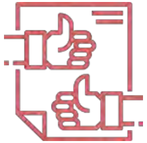
Angels (passion) vs VC (structured) plus other ways to raise (i.e. crowdfunding, etc)

Convertibles (simple) vs Equity (complex), Dilution, Valuation pre or post (prefer)

HOW IT WORKS

Interactions with investors

Founders and Investors



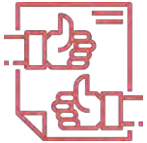
Meeting investors: be prepared, simplify pitch (first minute, don’t be boring, storytell/demo/prototype (prefer), listen)

You will be hearing many No’s. Pitch decks are reference points only. Meeting the founders is the secret sauce

https://www.ycombinator.com/library

An example

Founders
and
Investors



Companies should think about selling 10-15% in a seed round and 15-25% in their A round (and about 7% if they go through an accelerator).

When these combine into one large initial round, I suggest trying to sell no more than 30% of the company in total.

Having a solid and clean Cap Table is critical