Ultra-Dense Networks

- another paradigm shift

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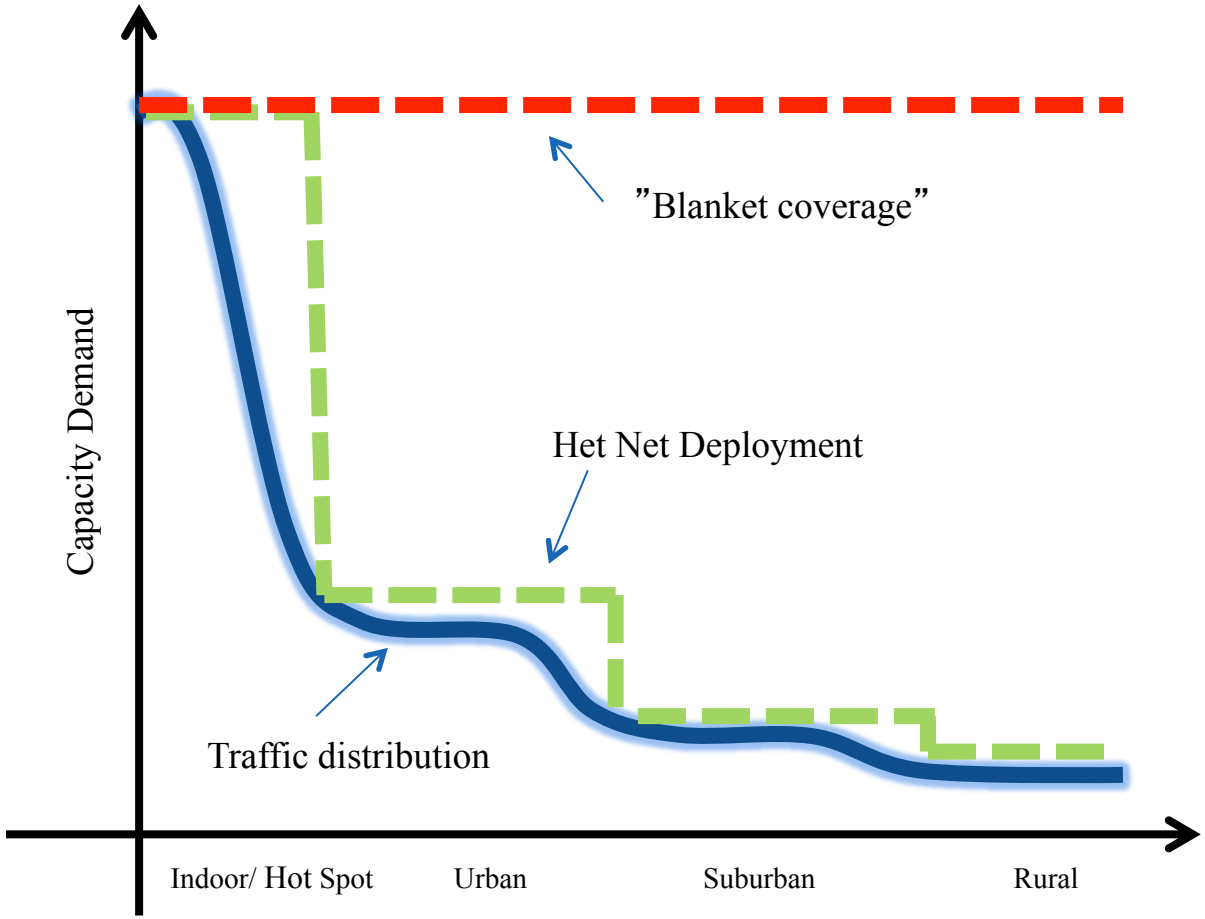
Outline

- **The “1000 times more capacity” challenge**
- **Ultra-Dense Networks**
  - What is an Ultra-Dense Network ?
  - Why does “cellular” technology not scale ?
  - What disrupts the ”cellular” business model ?
- **Scalable architectures for UDN:s**
- **Is spectrum an issue ?**

How to lower the cost:

”HET NET”s – deploy according to demand



The Light Analogy

Outdoor – Wide Area

- Indoor – Short Range

Why do the cellular concepts not scale?

The coverage world

Who: Public operators

- **Access any-time, anywhere**
- ”Insurance” – guaranteed access at moderate datarates (<10Mbit/s)
- Monthly fee
- Power/Site/Backhaul
- Limited spectrum – advanced SP&RRM
- Cost proportional to capacity
- Exclusive spectrum licensing – spectrum sharing

The capacity world

Who: Facility owners

- Local access
- Sanitary requirement / no charge
- User experience – high data rates
- Ultra dense deployment – Interference
- Low power, ”no” site cost, existing backhaul
- Simple distributed RRM – ”lots of” spectrum
- Cost increasing linearly with capacity
- ”Post-code licensing” – infrastructure sharing

Different business models – different engineering problems

What is discussed at

3GPP meetings

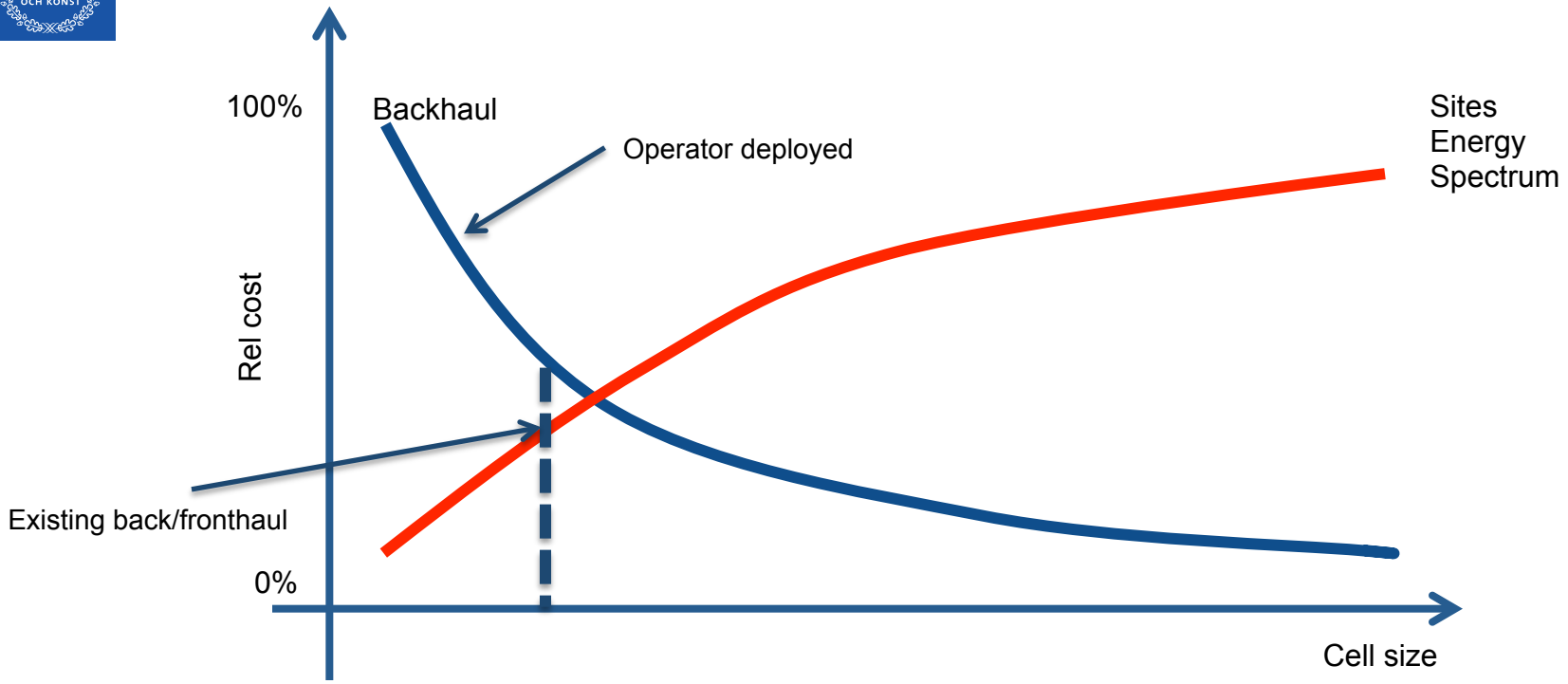
- Performance
  - Data rate
  - Area capacity,
  - Spectrum efficiency
  - Power consumption
  - Spectrum
- ”Mandatory complexity”
- Advanced RRM & SP
- Network Architecture

IEEE 802.11x meetings

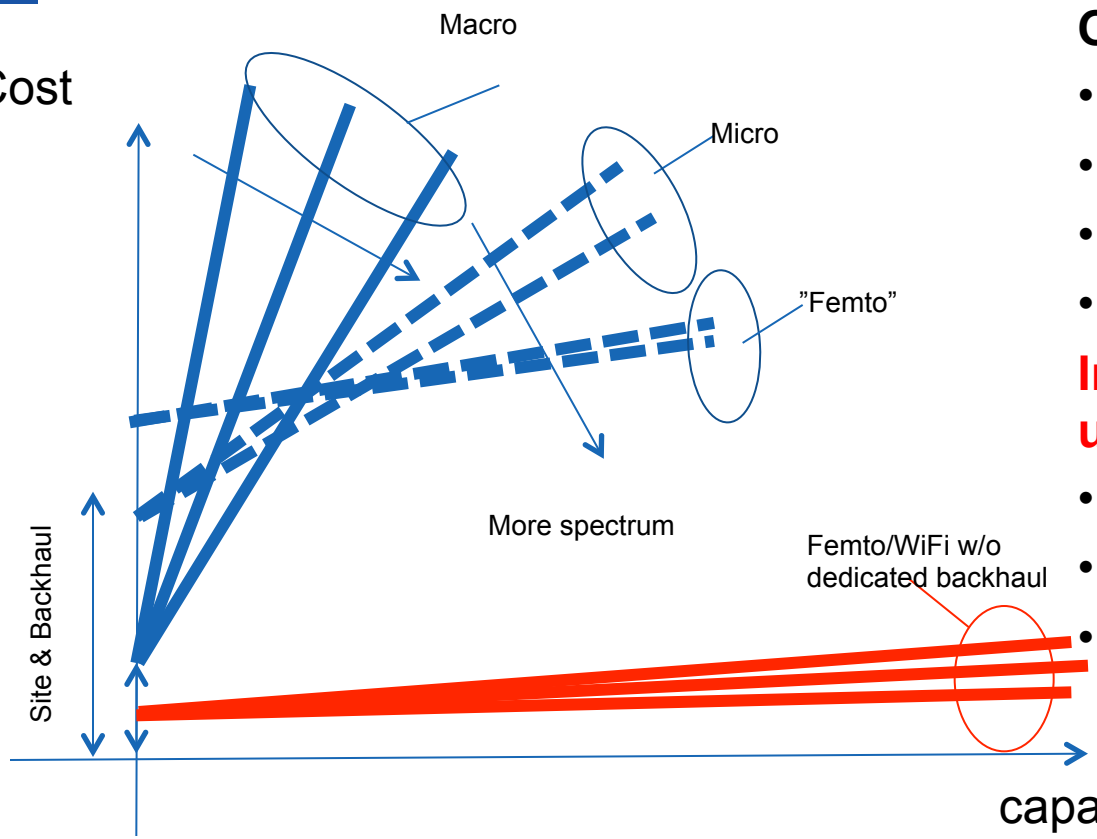
- Peak data rates
- Low complexity
- Time to market

Different business models – different engineering problems

Cost factors



The cost for capacity



Outdoor Macro/Micro

- Site aquisition
- Backhaul
- Outdoor equipment
- Wall penetration loss

Indoor Femto/WiFi using existing backhaul

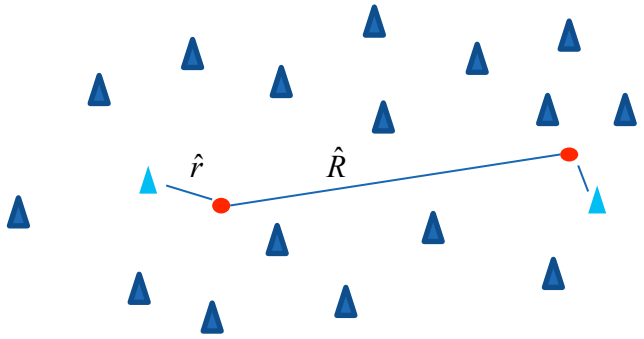
- Cheap equipment
- No dedicated backhaul
- Wall loss = benefit!

Capacity (were needed) is ”cheap” - coverage is expensive

Ultra – Dense Networks

- (Considerably) More base stations than user terminals
- Engineering/Techno-Economical issues:
  - Backhaul cost/limitations
  - Interference management
  - (Idle) power management

UDN capacity limits – ”Rough” SPPP analysis



$$\hat{R}: \mathrm{F}_{\hat{R}}(r) = \Pr\left[\hat{R} \le r\right] = 1 - \left[\text{no active BS within r}\right] = 1 - e^{-\lambda_U \pi r^2}$$

$$\hat{r}: \mathrm{F}_{\hat{r}}(r) = \Pr\left[\hat{r} \le r\right] = 1 - \left[\text{no BS within r}\right] = 1 - e^{-\lambda_B \pi r^2}$$

$$\bar{R} = E[\hat{R}] = \int_0^\infty r f_{\hat{R}}(r) dr = \int_0^\infty 2\pi\lambda_U r^2 e^{-\lambda_U \pi r^2} dr = \frac{1}{2\sqrt{\lambda_U}}$$

$$\bar{r} = E[\hat{r}] = \frac{1}{2\sqrt{\lambda_B}}$$

Downlink SINR: $$\Gamma = \frac{cP\frac{1}{r^\alpha}}{\sum cP_i \frac{1}{R_i^\alpha} + N} \approx \frac{cP\frac{1}{\bar{r}^\alpha}}{\lambda_U cP \frac{1}{\bar{R}^\alpha} + N} = \frac{\lambda_B^{\alpha/2}}{\lambda_U^{1+\alpha/2} + \frac{N}{c'P}}$$

For fixed maximum rate R_{max}:

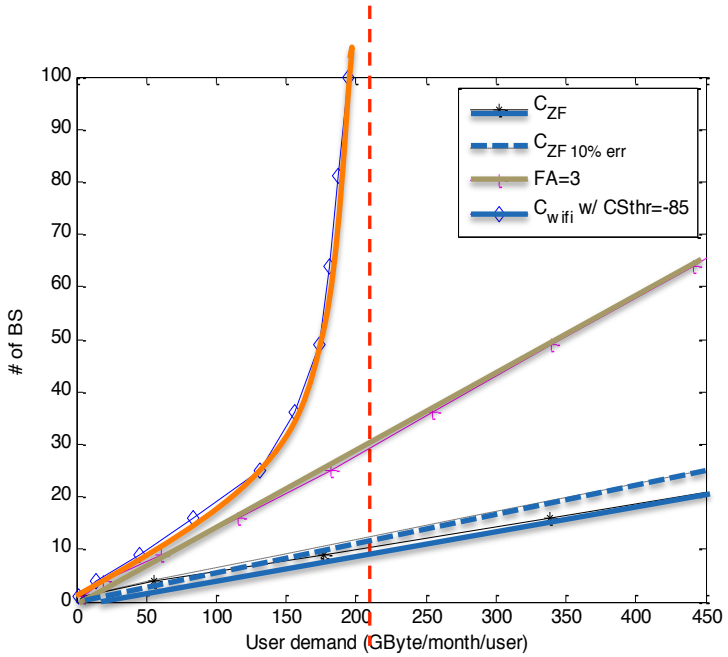
$$\text{Area capacity} \propto \begin{cases} \lambda_U \log(1 + c\lambda_B^{\alpha/2}) & \lambda_B \le \lambda_B^*(R_{\max}) \\ R_{\max}\lambda_U & \lambda_B > \lambda_B^*(R_{\max}) \end{cases}$$

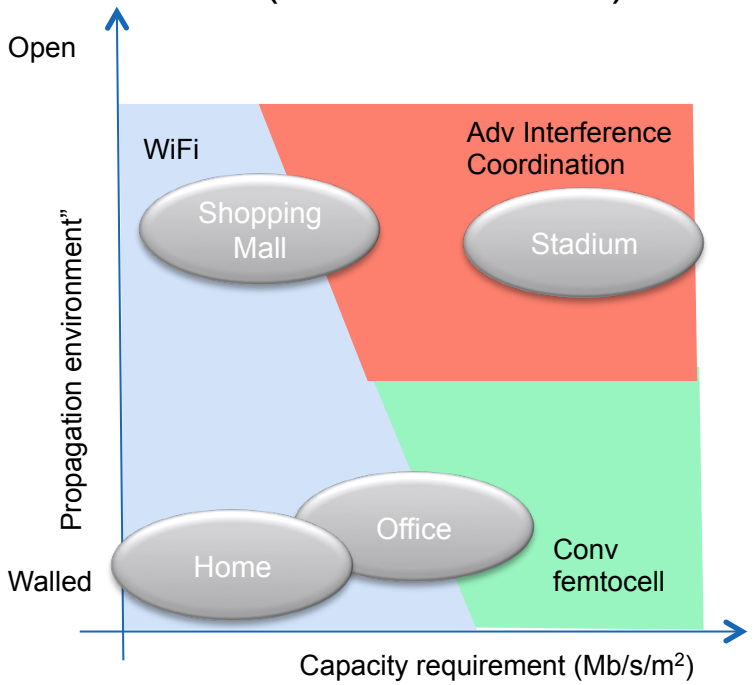
Control/Data-plane separation → efficient sleep modes

Tx power consumption $\rightarrow c\frac{\lambda_U}{\lambda_B^{\alpha/2}}$ Idle power consumption $\rightarrow c'\lambda_B$

Advanced interference coordination ?

More access points - or more expensive backhaul (for coordination) ?





Kang, Sung, Zander, "High capacity indoor and hotspot wireless systems in shared spectrum: a techno-economic analysis", IEEE Com Mag, Dec 2013

Where are we heading - spectrumwise?

Wide area access

Spectrum need to lower infrastructure cost

Block-licensed spectrum to match long-term RF-specific investment (<3 GHz)

Repurposing of UHF from TV -> IP access

- Digital dividends 800, 700, 600 MHz etc

Short range access

Plenty of potential spectrum <20 GHz

Higher frequencies (>3 GHz) for high capacity (lower interference)

Local & temporal spectrum regimes (National Block-licensing inefficient)

Unlicensed, Secondary, LSA, ”Instant licensing”

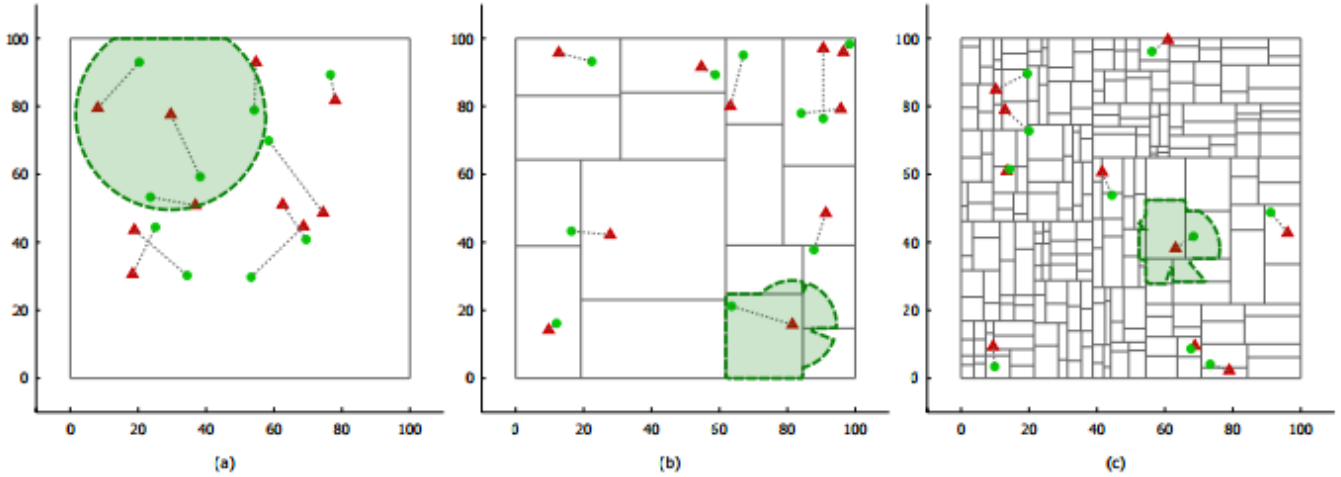
Infrastructure vs Spectrum Sharing ?

Modelling issues

SPPP-models conveniant – mathematically – but do they capture essential features of dense indoor deployments ?

- Strong interference coupling between BS
- Walls – simple deployment strategies take these into account

Alternative approach – stochastic room/wall models



Özyagci, Sung, Zander, “Effect of propagation environment on area throughput of dense WLAN deployments”, Globecom BWA WS, 2013

Conclusions

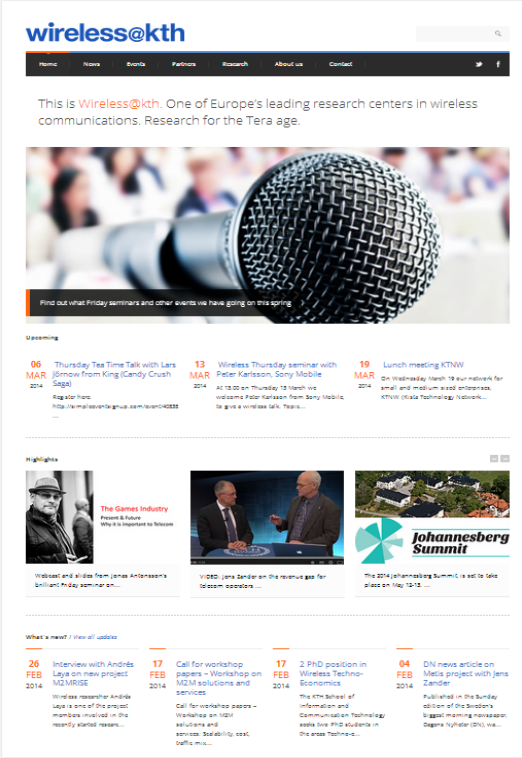
Ultra-Dense Networks Indoor = paradigm shift required

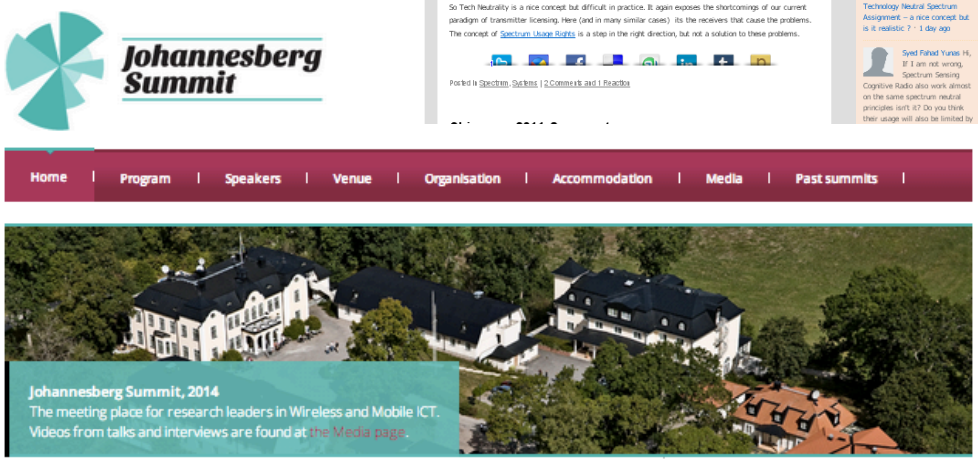
- New techno-economical challenges: the old cellular solutions not appropriate
- New spectrum licensing regimes
- New system modelling tools required

Read more !

theunwiredpeople.com

wireless.kth.se





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Everything under one roof ?
Transparancy vs Efficiency

The IP-access world

- Large volumes of standardized equipment, unified platforms
- Low efficiency, overprovisioning of resources
- Willingness to pay for flexibility

The MTC world

- Large volumes
- Very diverse requirement on power, delay, cost…
- Non-standardized equipment, no unified platforms
- Rational decisions based on savings