Wireless Technology: evolution, standards and future trends

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Agenda

Market forces

- STEEP categories
- Analyzing the forces
- Dialogue

History and standardization

- History of personal wireless
- Standards
- Dialogue

Future trends for technology

- The next ten years
- Dialogue

Market Forces

Looking Ahead

- Look to the forces that constrain the industry, not necessarily to where the industry thinks it is going in the next ten years
- Plan scenarios that build models around five force categories:
  1. **Sociological**
  2. **Technological**
  3. **Economic**
  4. **Environmental**
  5. **Political**

$$f_0 \wedge f_1 \wedge f_2 \ldots \wedge f_N \rightarrow C$$

- Use indirect observation

Analyzing Market Forces

Primary research

- Interview industry and domain experts to identify constraints, trends, uncertainties

Secondary research

- Review literature for quantitative values for identified constraints, trends, and uncertainty

Model building

- Construct mathematical models
- Analyze data to quantitatively identify the relative importance of each force

Fundamental multiple regression analysis...

Estimate the predicted outcome

Based on multiple quantitative causal factors

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \ldots \hat{\beta}_N x_N$$

Using minimum mean squared error fit

Sometimes, transforms are needed...

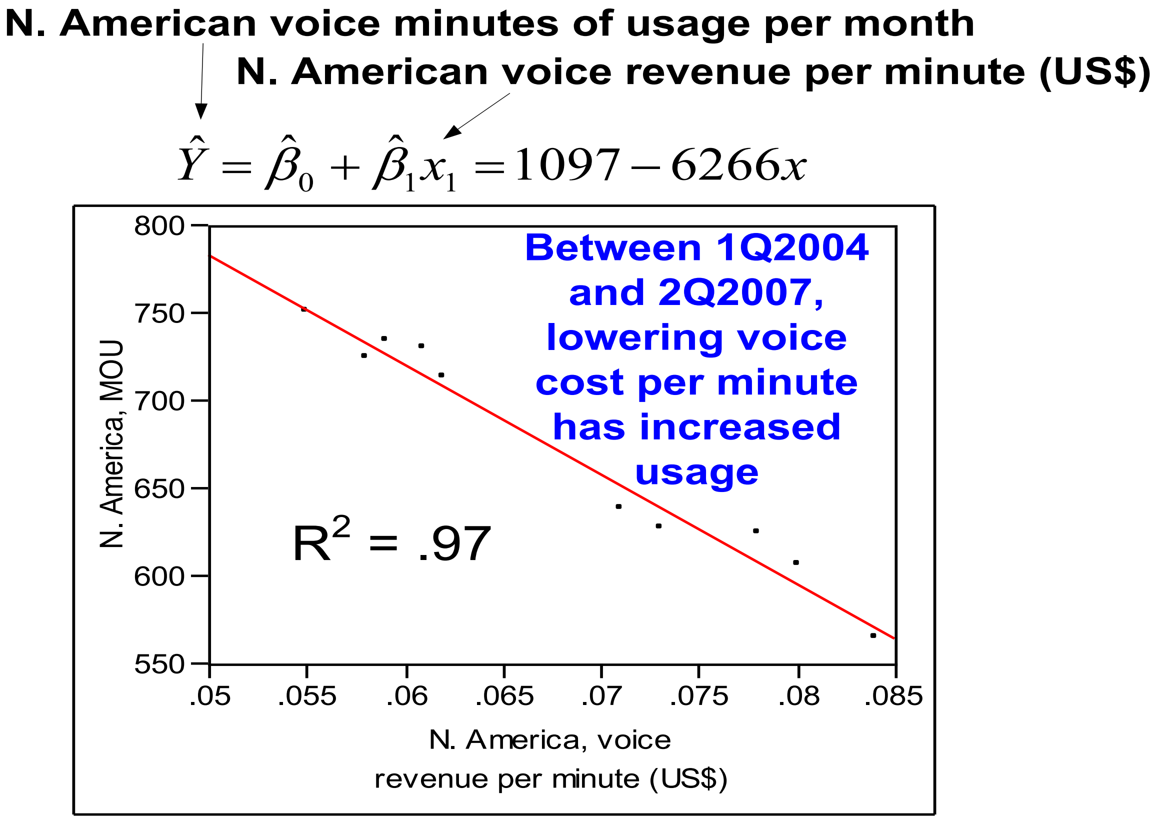
$$\log\left(\hat{Y}\right) = \hat{\beta}_0 + \hat{\beta}_1 \frac{1}{x_1} + \hat{\beta}_2 x_2^2 + \ldots \hat{\beta}_N e^{x_N}$$

* Coefficient of determination (R^2) measures how much each causal element explains the estimated outcome

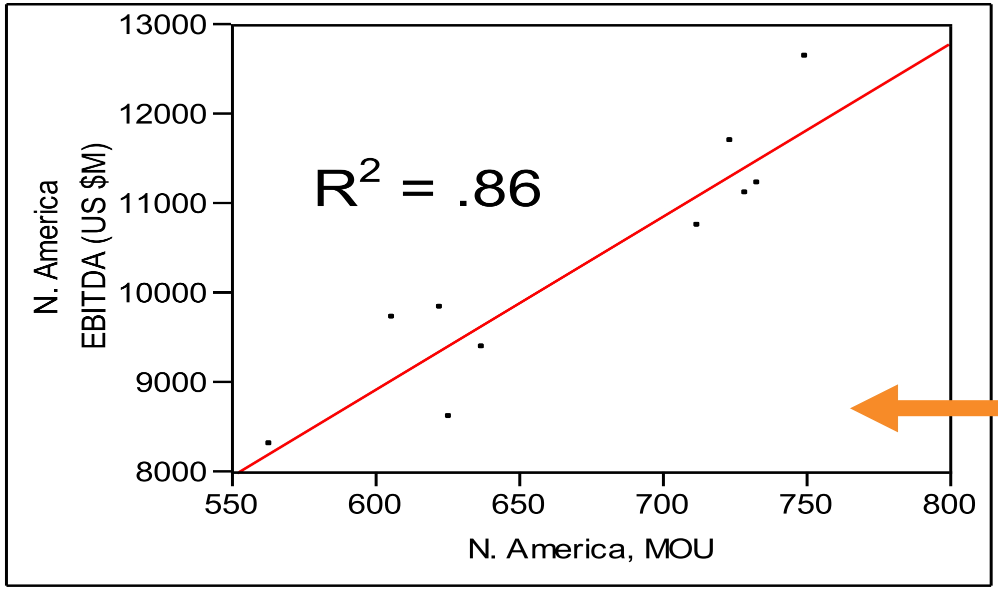
* Correlation coefficient measures how the causal elements are related

Quantitative Model

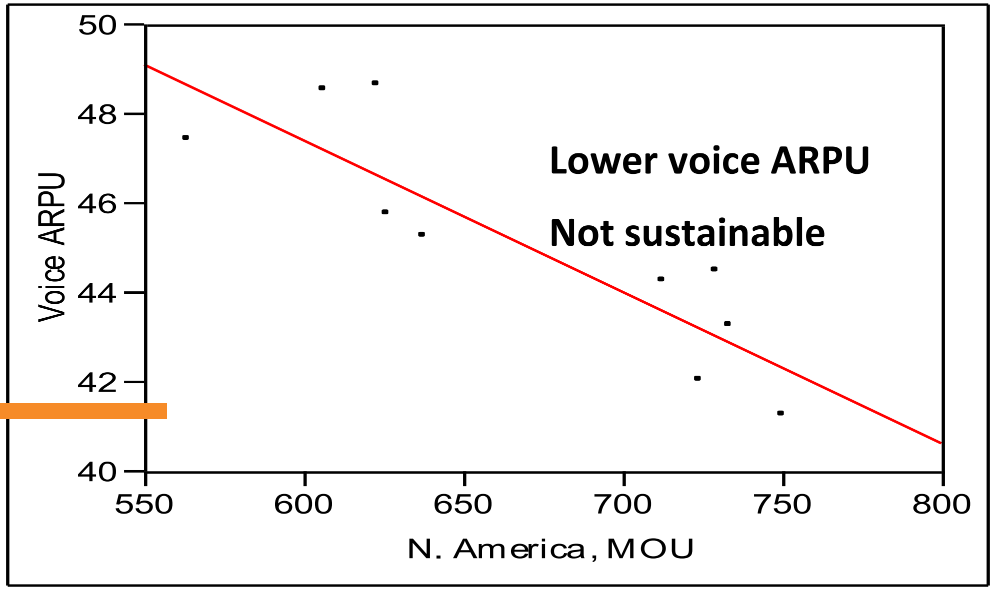
- Radio spectrum availability is a constraint to wireless revenue growth
- North American wireless network operators force monthly minutes of **voice usage up by lowering prices**
- Lower prices = more minutes consumed



Profits?



Non causal



Voice call profits are up for now, but not sustainable – wireless broadband consumes a lot of spectrum

So how did operators deal with this? -> Data Roaming!

STEEP

Sociological: user expectations, information security, social networking

Technological: spectrum availability, battery life, user mobility

Economic: switching costs, consequences of long-term asset acquisition, intellectual property costs

Environmental: manufacturing, battery and equipment disposal

Political: spectrum regulation, licensing regulation

Sociological Forces

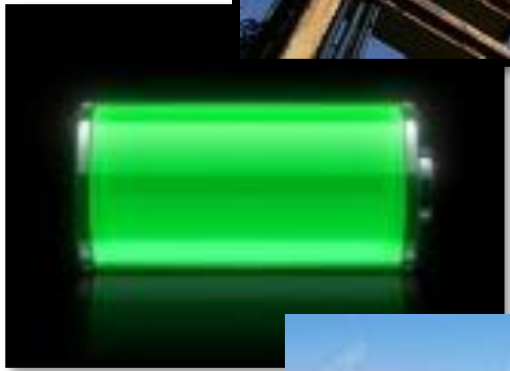
- User expectations
- Information security
- Social networking/media
- Mass collaboration
- User generated content

Technological Forces

Spectrum availability
- Notion of appropriateness for cellular spectrum
- 700 MHz to 60+ GHz
- *Spectrum pollution* in unlicensed services in some areas of high population density

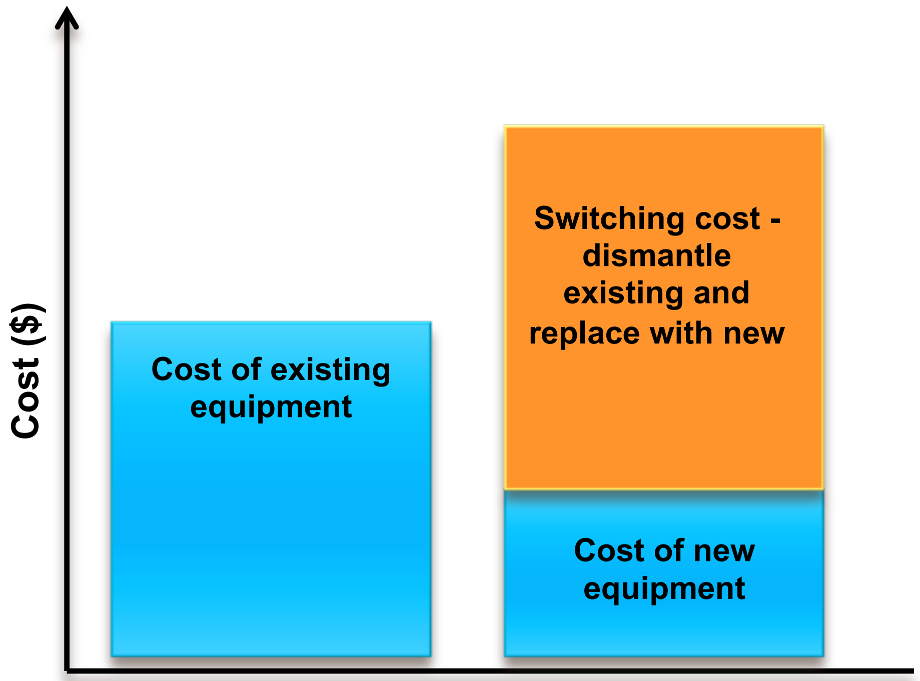
Battery life
- Growing processing capabilities and application demands conflict with the slower development of battery technology

User mobility
- Greatest strength and weakness
- Primary problem: users are mobile and uncontrolled
- Trade-off between mobile user experience and practicality


Economic Forces

Switching Costs



"The new technology is better and cheaper, but we cannot afford to unplug the existing system…"

Asset Efficiency

- Capitalized assets are available for the public, investors and analysts to scrutinize
- Trend toward managed networks – leasing models
- Players think twice about equipment investments

Intellectual Property Rights (IPR)

- Operators and manufacturers may not be able to earn economic profits using certain technologies due to excessive demands by patent trolls
- Economics of industry may not support the royalty structure requested by IPR holders

Environmental Forces

Disposal of substances:

- Batteries
- Displays
- Chemicals used in manufacturing
- Plastics
- Heavy metals used in semiconductors

Political Forces

Spectrum regulation

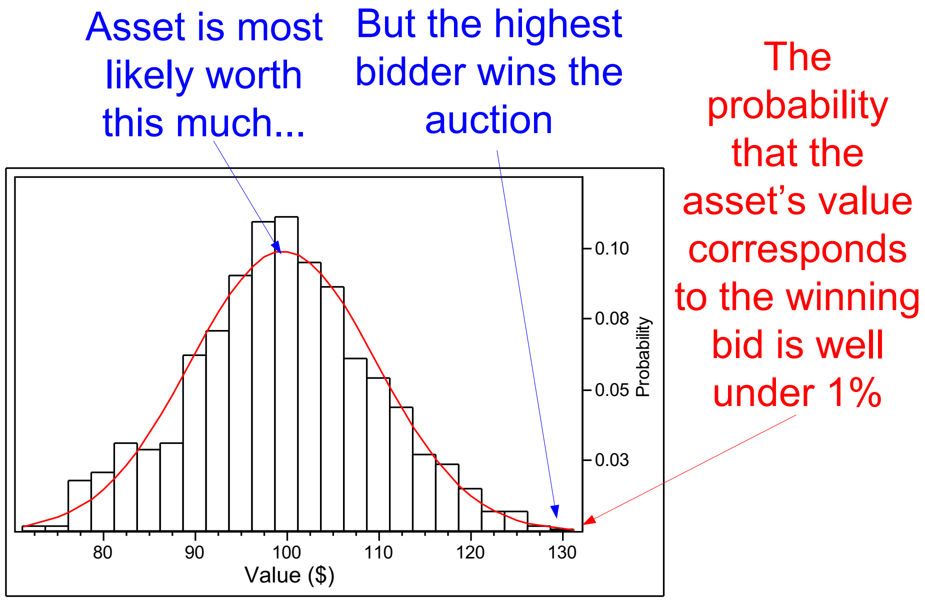
- Re-farming spectrum = vacating existing users
- Economic benefit?
- Economies of scope exist when multiple countries share the same frequencies for the same services > can we agree on way forward?

Licensing regulation

- Should a license anticipate a particular technology?
- Winner’s Curse

Global technology regulation

- Technology *legal* in some countries and *illegal* in others
- Manufacture and sell in all target countries?



The winner’s curse in an English auction

Dialogue

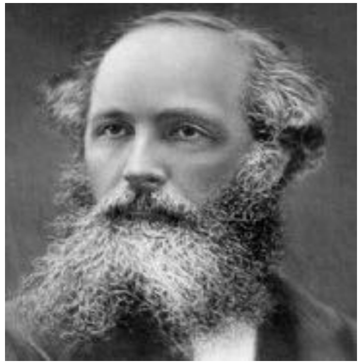
1. What other forces in the STEEP categories might impact the wireless industry?
   - In conjunction with your own industry?
   - In the wireless world in general?

2. How might the forces differ from one geographic region to another?

History and Standardization

The idea of wireless emerges: around 1861

- By the year 1850, most electrical phenomenon had been investigated by academic researchers
- James Clerk Maxwell (1831-1879), Professor of Experimental Physics at Cambridge introduced a new model for examining both electrical and magnetic phenomena
- His new mathematical model, today referred to as Maxwell's equations, predicted that there might be the existence of electromagnetic waves



$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$

$$\oint \mathbf{B}\cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

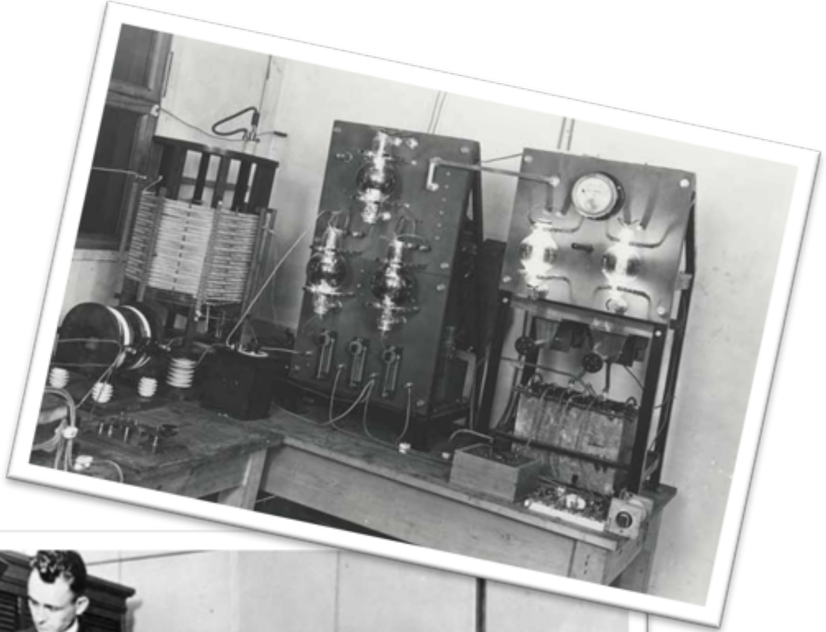
$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

Early Wireless

- **Hertz** and **Popov** did lab experiments circa 1891
- Nikola Tesla filed patents on radio starting in 1892
- First commercial wireless technology deployments
  - Based on the work of **Guglielmo Marconi** (filed first patent for wireless telegraph system in the UK in 1896)
- First broad commercial application was ship-to-shore telegraphy
  - International Yacht Races held off New York Harbour in 1899

1920s: Voice Radio

- Reliable systems for transmitting and receiving voice information developed
- Vacuum tube technology was the relevant art
- One-way commercial radio broadcasting
- Two-way commercial and military communication systems
- Rapid adoption during the 1920s through 1940s
- Radio was the *Internet of the 1920s*



1950s and 1960s: 1st mobile telephones

MTS: Operator-assisted dialing

IMTS deployed in the USA in 1969

1970s and 1980s

- Rapid adoption during the 1970s
- Everyone wanted one!
- Execs underestimated the demand
- Insufficient capacity
- Only a few phone numbers
- By 1980, 5-year waiting list in major cities in Europe and North America

1G Cellular Technology

- New technologies: mobility management, handover
- 1983 - AMPS launched in Chicago
- Business and professional market segments
- Lots of phone numbers

2G Digital Cellular

- Global digital cellular standard introduced
- Developed in Europe in the late 80s, early 90s
- System turned on in Europe in 1992
- GSM Phase 1 supported voice and SMS

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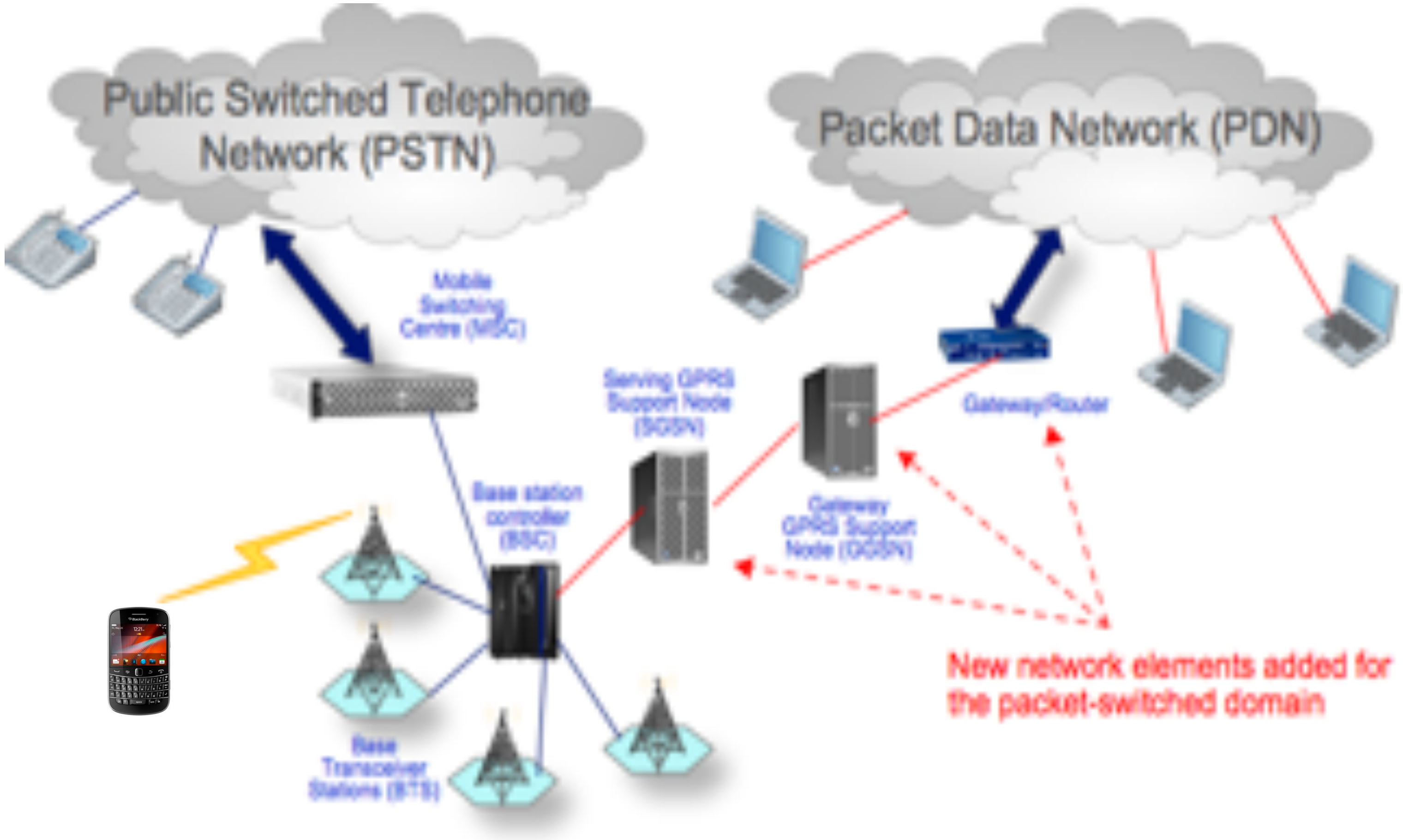
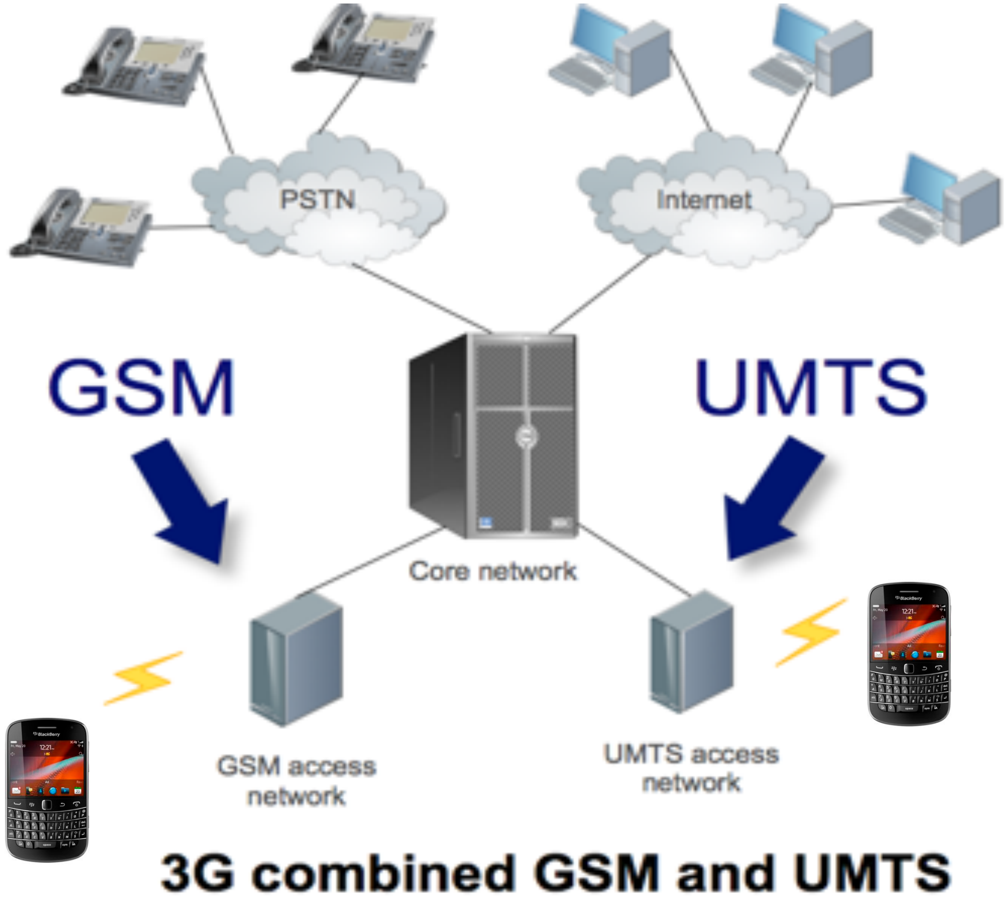
GSM enhanced in 90s with GPRS and EDGE

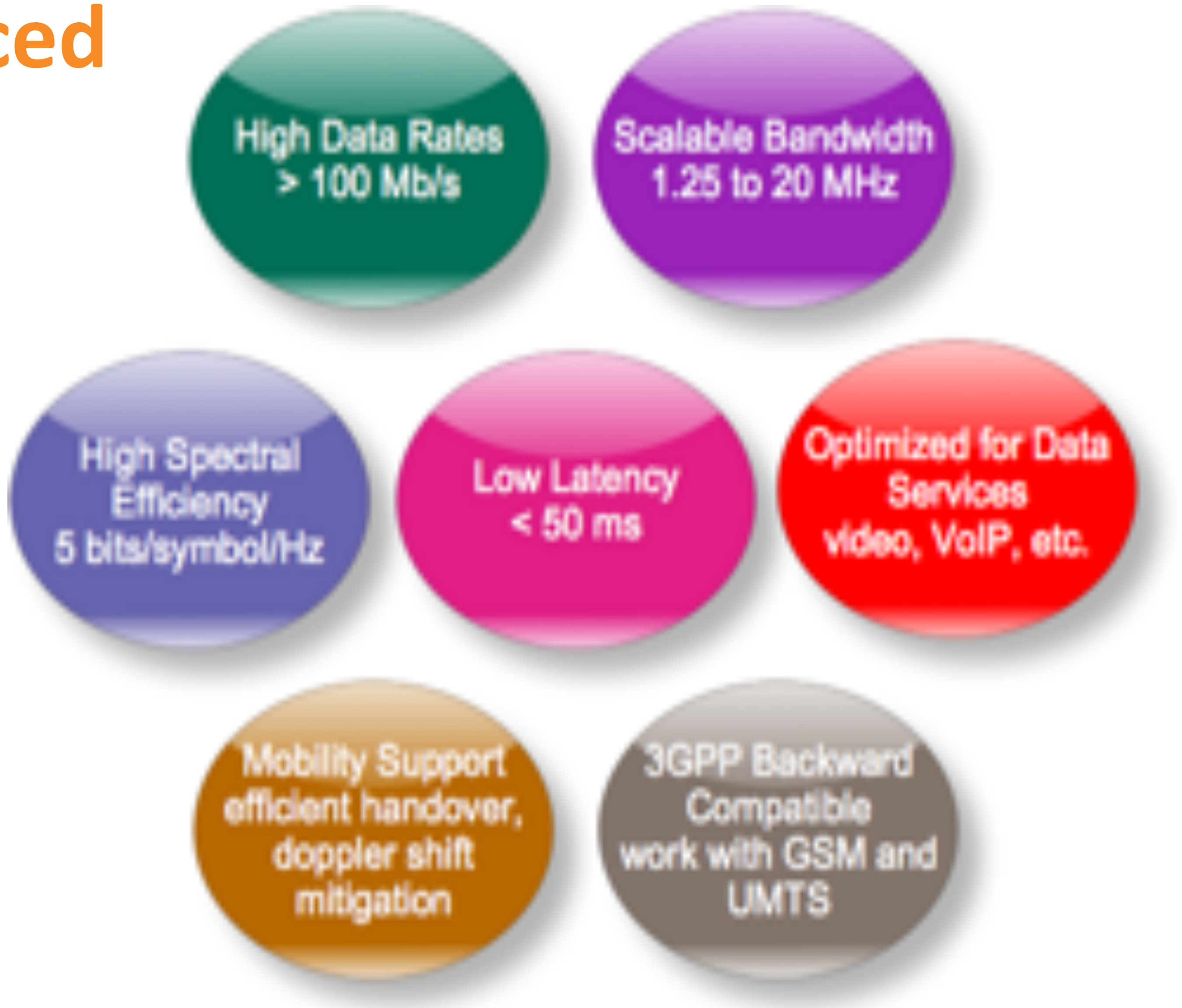


3G



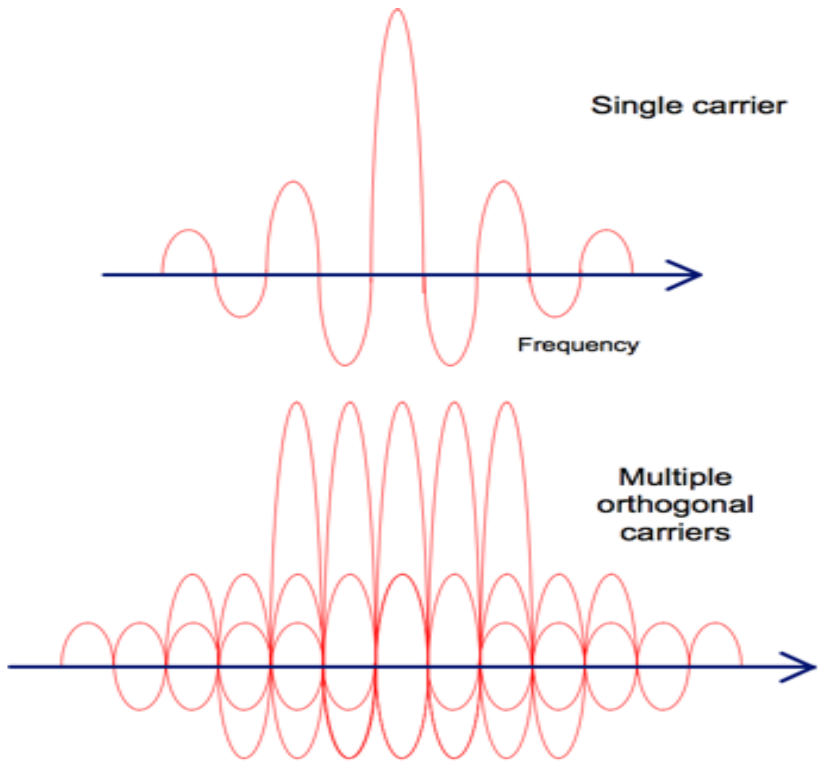
- 3rd Generation Partnership Project (3GPP) founded in 1998
- 3GPP combined GSM and future standard for 3G
  - First UMTS
  - Next HSPA

4G LTE/LTE-Advanced



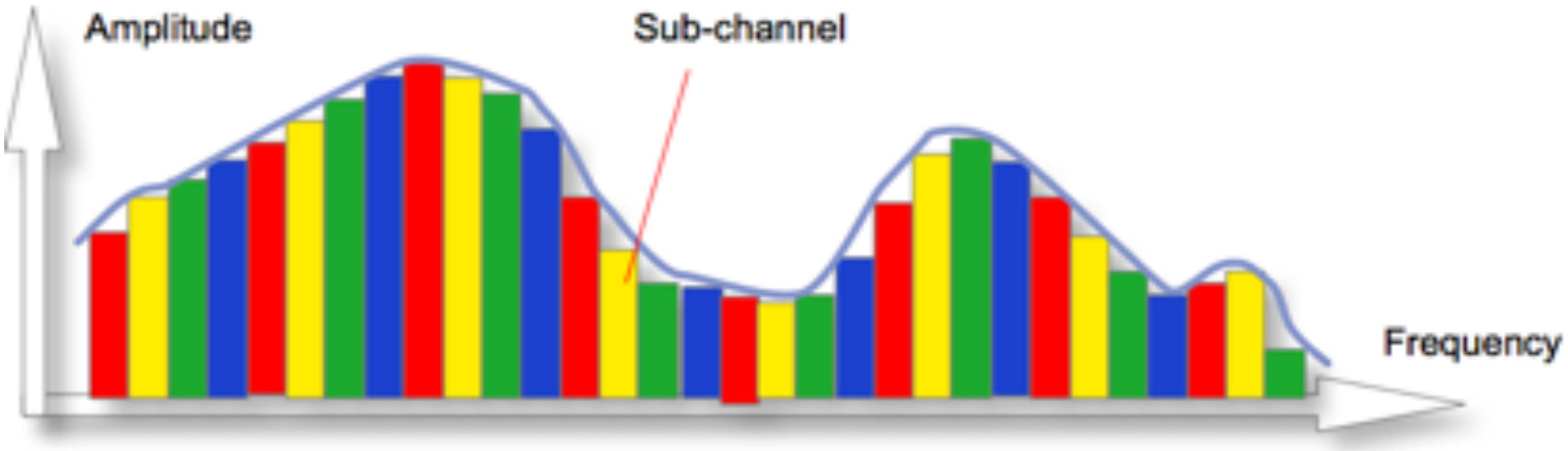
LTE and LTE-Advanced

- Standardization work in 3GPP (GSM and UMTS)
- Interoperability with GSM and UMTS
- Orthogonal Frequency Division Multiplex (OFDM)
- Multiple, carriers – sync shaped spectra, mathematically orthogonal
- No ISI
- Fast serial data stream transformed into slow parallel data streams

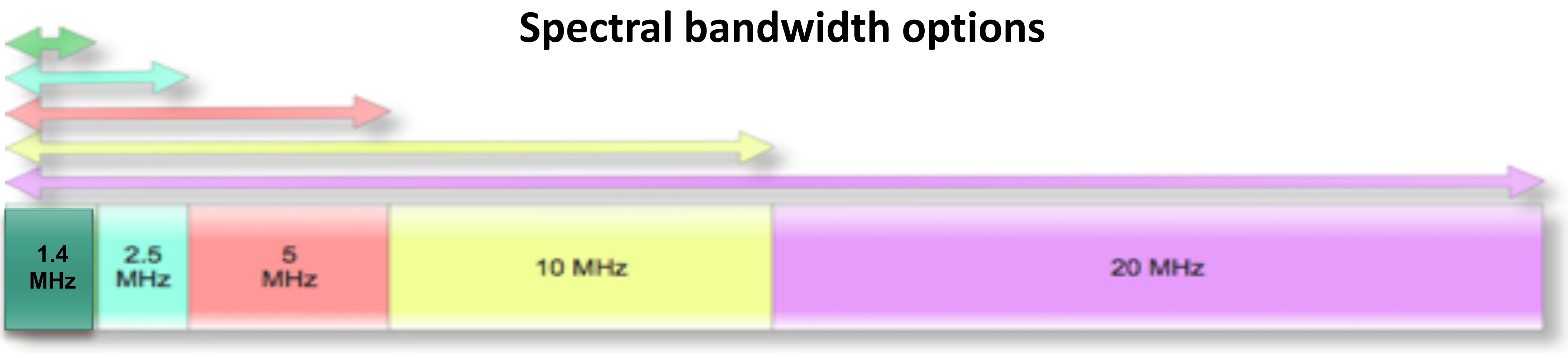


OFDM Sub-channels

- Small sub-channels
- Easier to handle mathematically
- Mitigates mobility related impairments

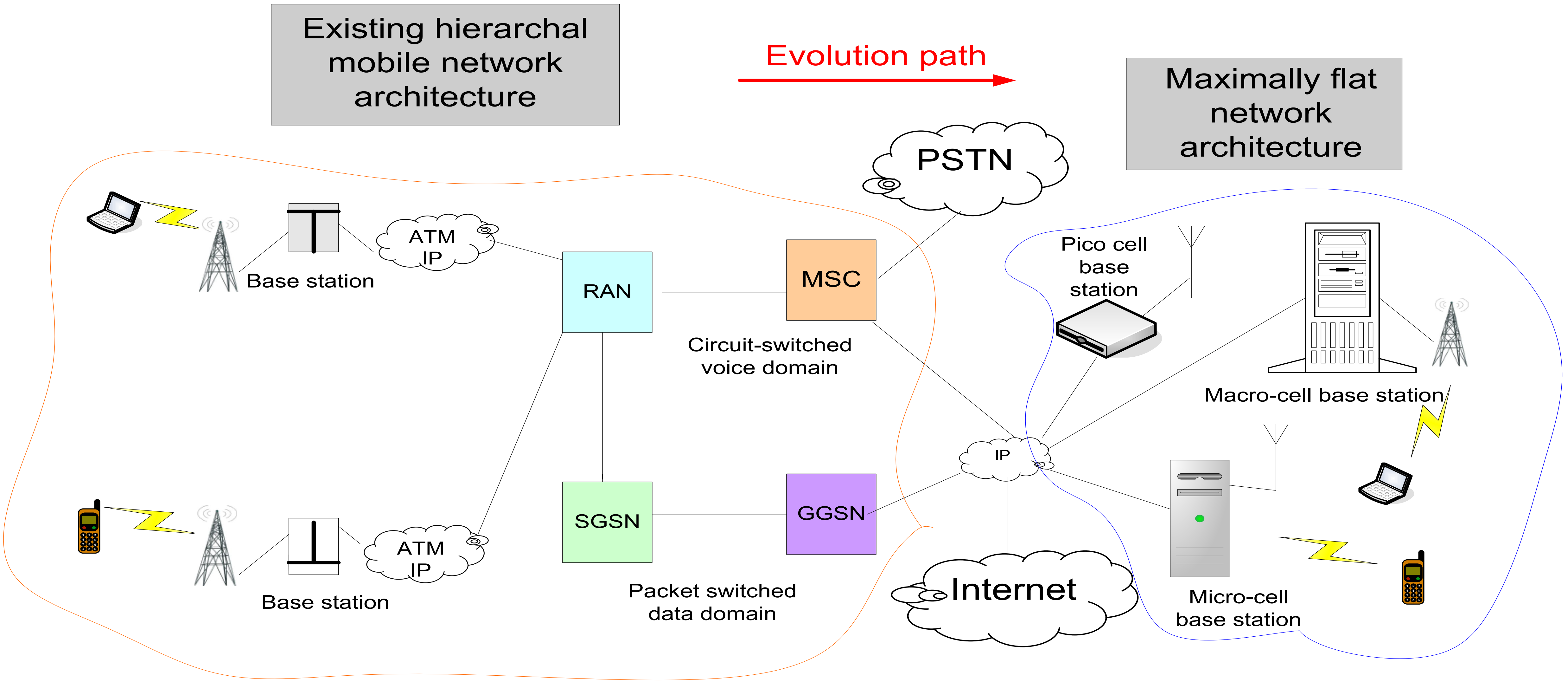


Flexible Spectrum

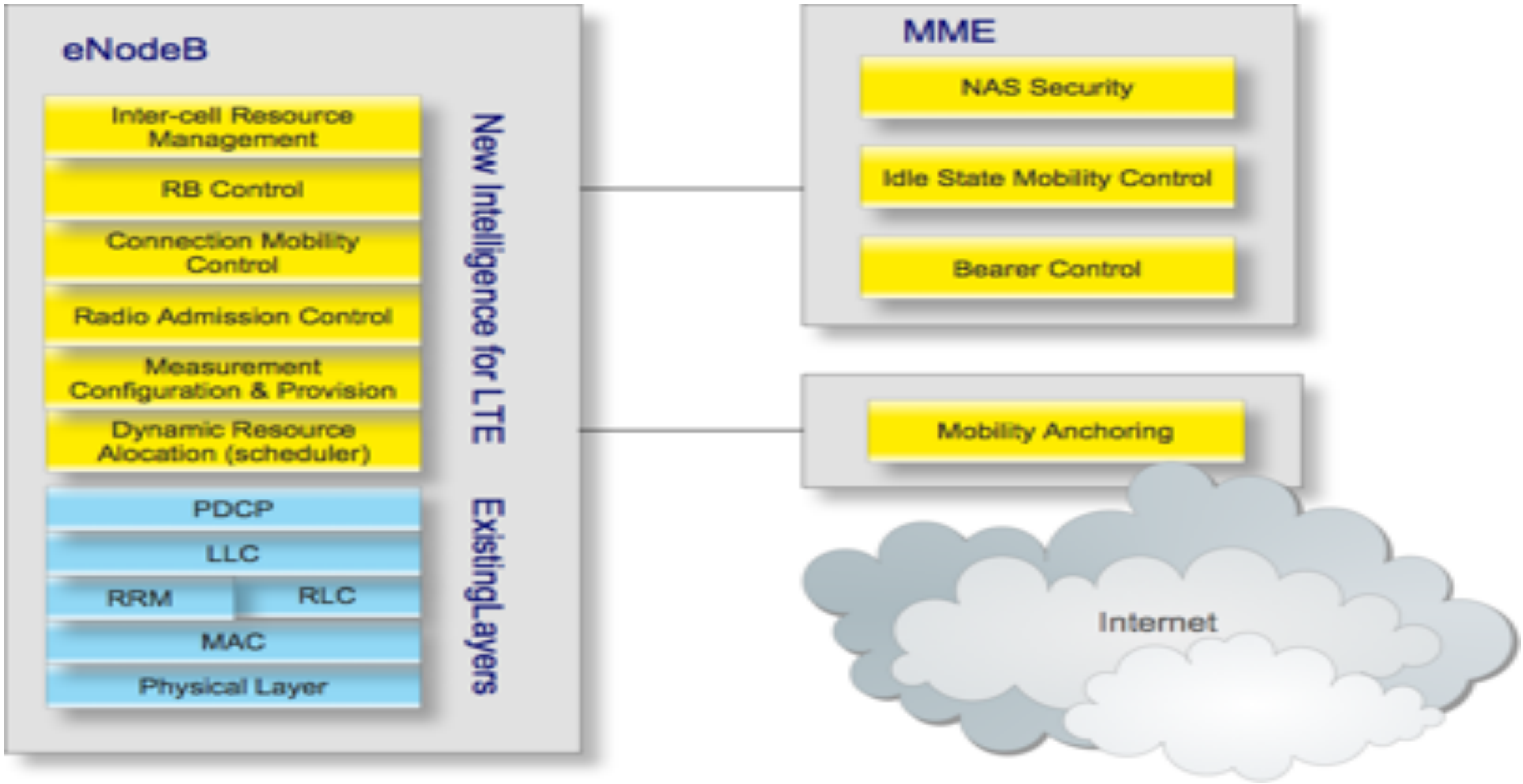


- The network operator can grow into available radio spectrum over time

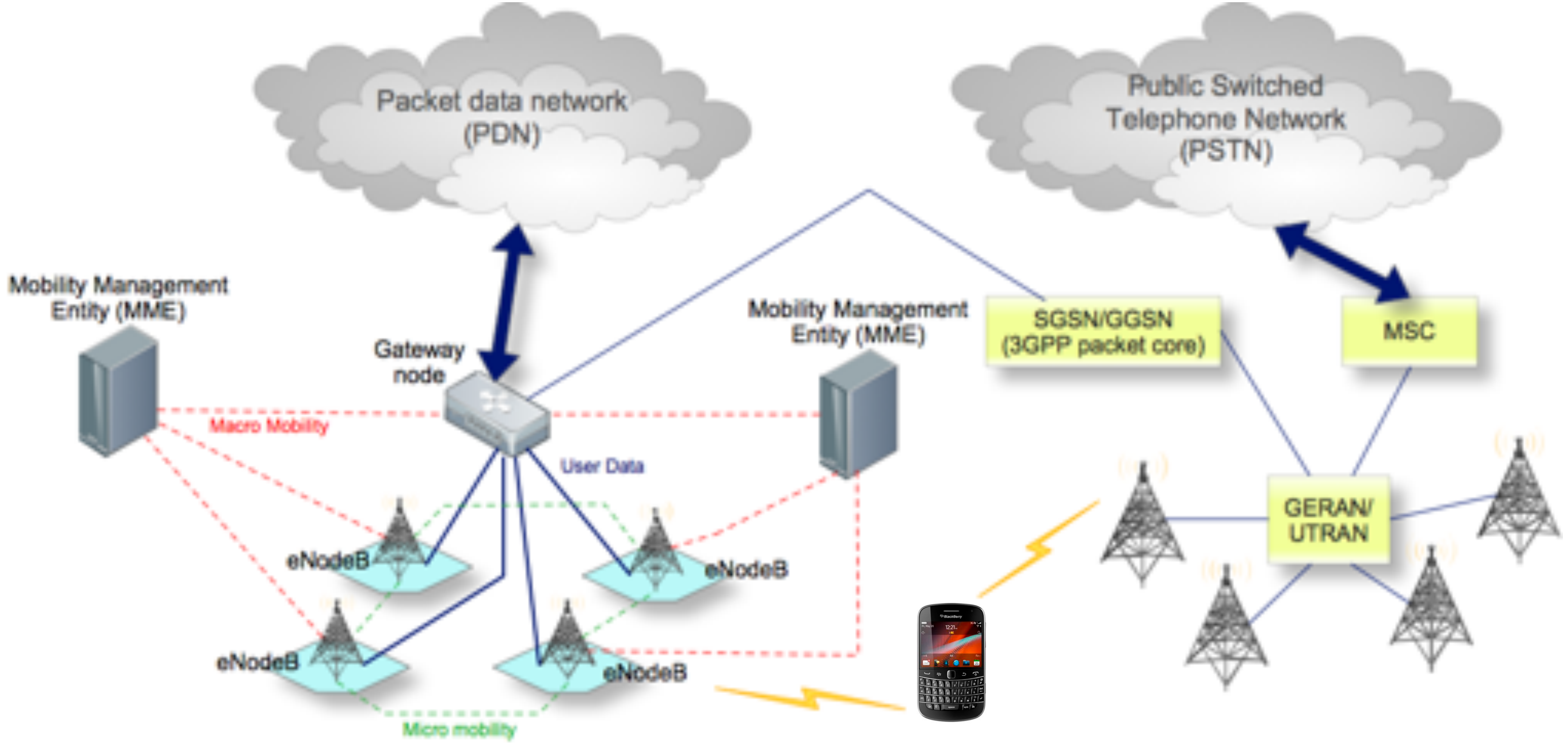
System Architecture



Ultra-smart Base Stations



Backward Compatible with GSM/UMTS



Then…

1950s – 1990s: a phone was just a phone

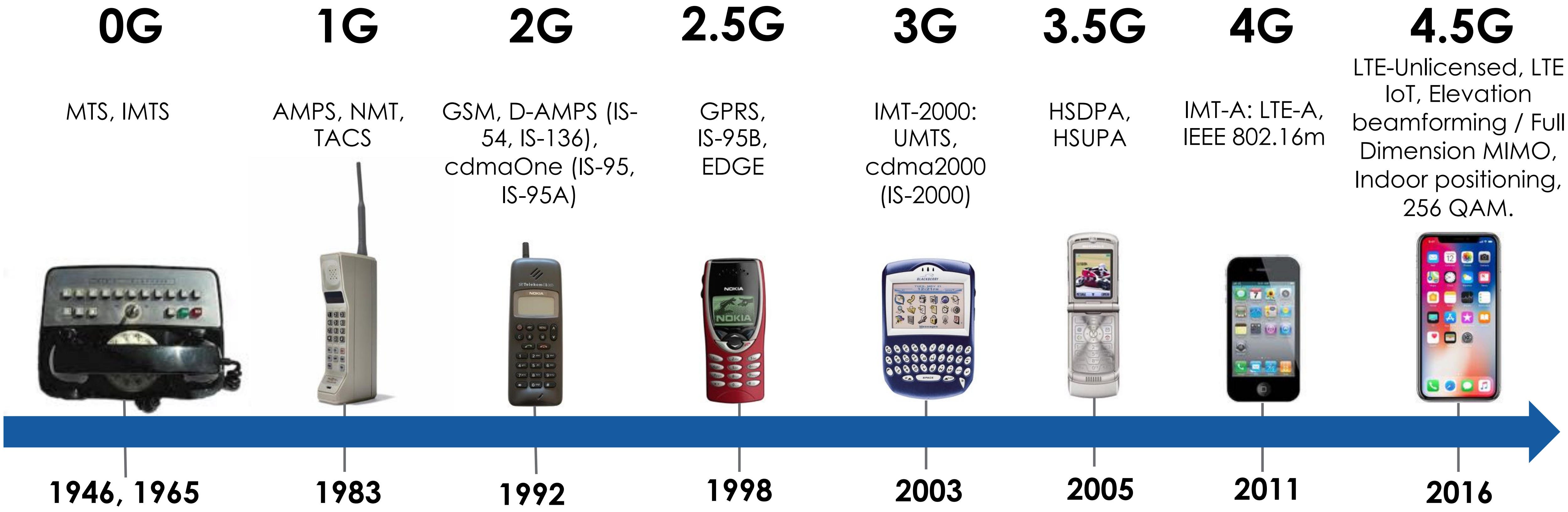
Around 2002: not just a phone;
email and messaging too

...and now – the smartphone, wearables & more

You can still make a voice call

Standards

The Evolution of Standards

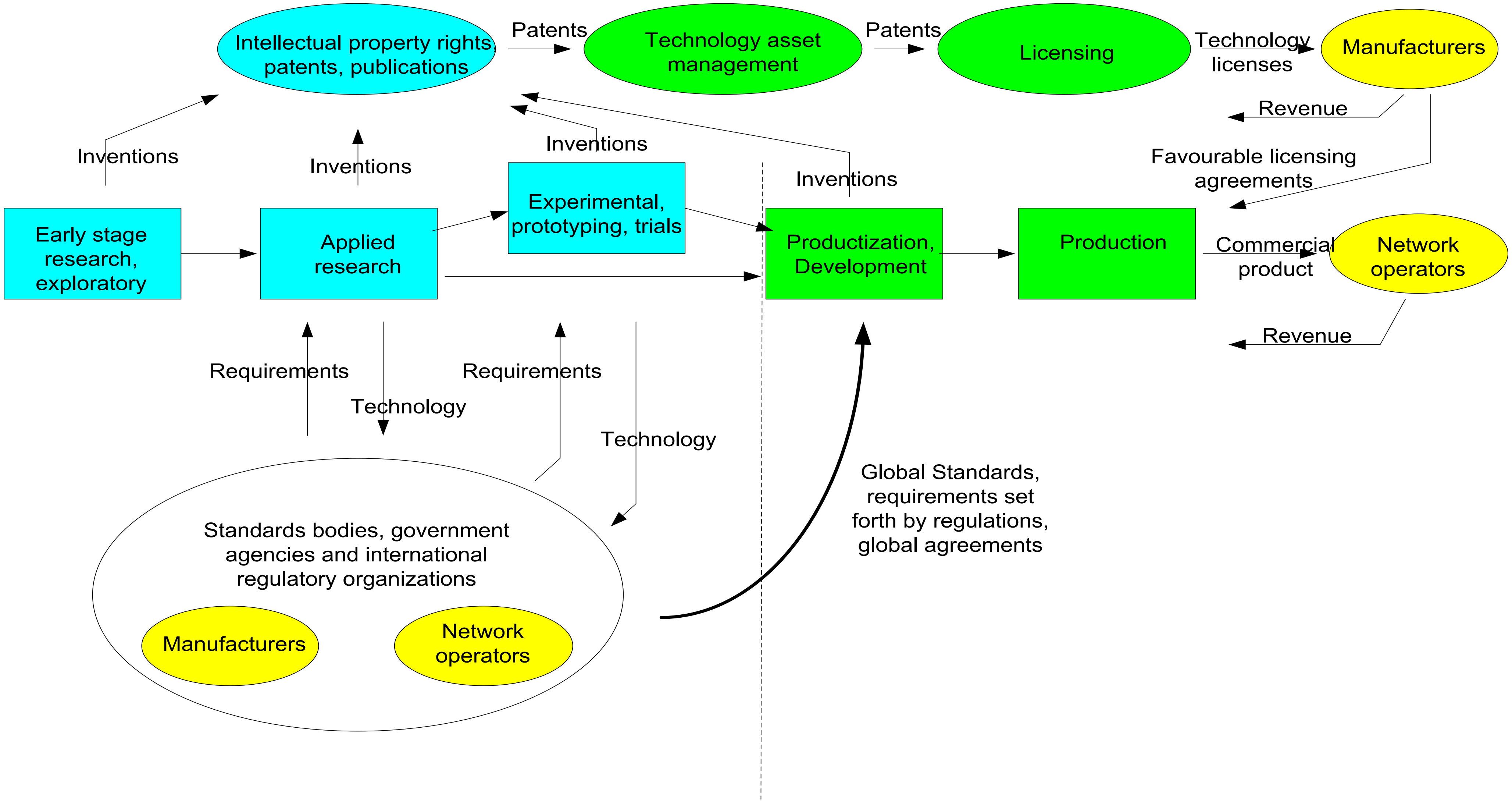


Standardization in Wireless

- Geographic and inter-system interoperability
- Economies of scale
- Economies of scope
- Large-scale adoption potential
- Double-edged sword
  - Give up proprietary advantages in exchange for possibility of creating large global markets
  - Innovation space is constricted to contain technology switching costs – the price you pay for large market creation

3GPP Technologies: 95+% of world market

How standards create value



Standards Bodies

- Industry consortia – Companies having complementary, or competing interests come together for industrial research collaboration
- Research cooperative groups created to develop and maintain standards

What happens in ETSI/3GPP?

- **Someone proposes a Work Item Description (WID)**
  - Examples: advanced receivers, GPRS, EDGE, HSDPA, RX Diversity, etc.
  - Rapporteur is assigned to edit the output docs; convene ad-hoc meetings
- **Companies meet in ad-hoc meetings (1 year+)**
  - Bring in proposed solutions
  - Simulation results
  - Liaison statements are written to, and received from, other working groups regarding any impact
  - Agree on general direction – output technical report (TR)

Drafting Standards

- **Core specifications are drafted**
  - Requirements and technical specifications are agreed upon and written into core specifications
    - Stage 1 – Service Description
    - Stage 2 – General architecture and requirements
    - Stage 3 – Detailed implementation requirements
- **Test specification work begins**
  - Test specifications are intended to enforce the requirements of the core specifications
  - Number of test spec CR's biggest predictor to adoption

Oversight

Contributions are agreed by working groups

For example, in TSG GERAN:

- Radio physical layer is handled by WG1
- Signaling is handled by WG2
- Testing is handled by WG3

Specification is approved by plenary

- Agreed specifications sent to plenary for final approval
- Version number assigned
- Specification placed in public directory

Work in a Standards Body

- Learn the business culture and procedures of participants
- Learn how the standards body operates at a procedural level – ETSI and 3GPP are consensus driven
- Identify key players and reach out to as many as possible
- Avoid slang and idioms
- NEVER send a new document to a meeting with a delegate or researcher, unless it has been sent out to the Working Group (WG) email list for comments/corrections
- Speak with credibility – meeting minutes are recorded and made public

To participate or not…

Question:

The standards process is expensive and time consuming. Why don't we let other companies standardize the technology, and then implement the standard after it is published?

Answers:

1. If your company does not participate in the development of standards, then your competitors will write your product requirements for you – and they won't make it easy given your existing architecture.

2. If you did not help develop the technology, then you will pay the contributors to the standard for royalties on their technology.

3. Blind implementation of a standard is almost impossible. Standardization is a mutual learning process - if your people did not develop competencies during standardization, you will almost certainly be late to market.

Wireless Security

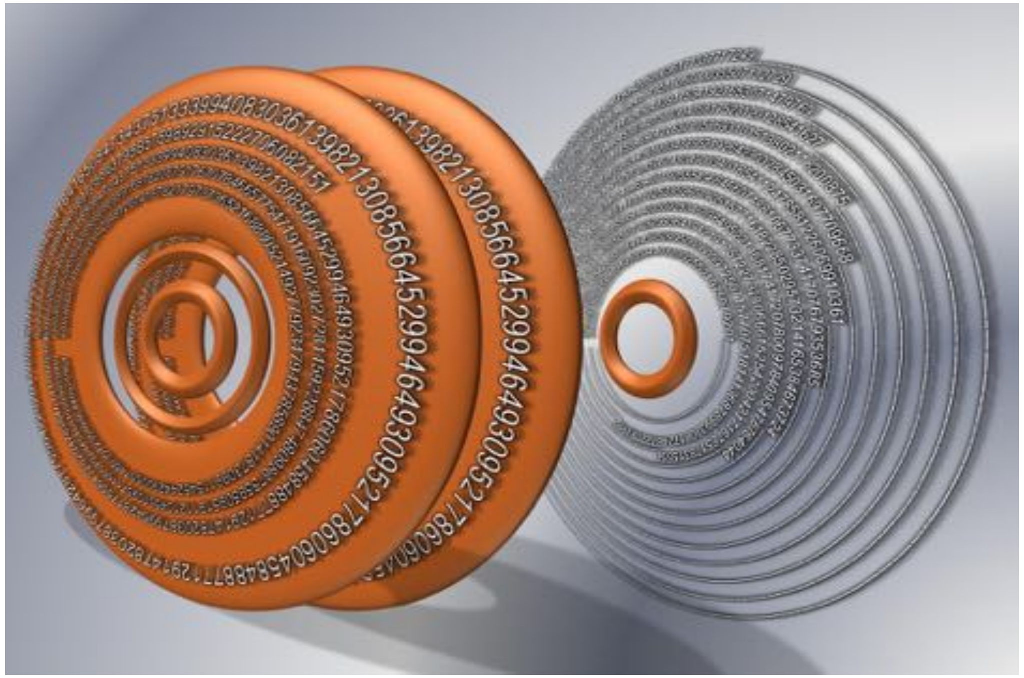
Wireless Security

- Cryptography is a key component of wireless security
- Includes public-key and symmetric key technology
- Provides the following:
  - Data authentication
  - Entity authentication
  - Confidentially (through encryption)
  - Non repudiation (through digital signatures)

Public Key Technologies

- Rivest, Shamir, Adelman (RSA)
- Most well-known public-key technology for conventional wired environments
- Not well-suited for wireless due to constraints of the environment

Public Key Technologies

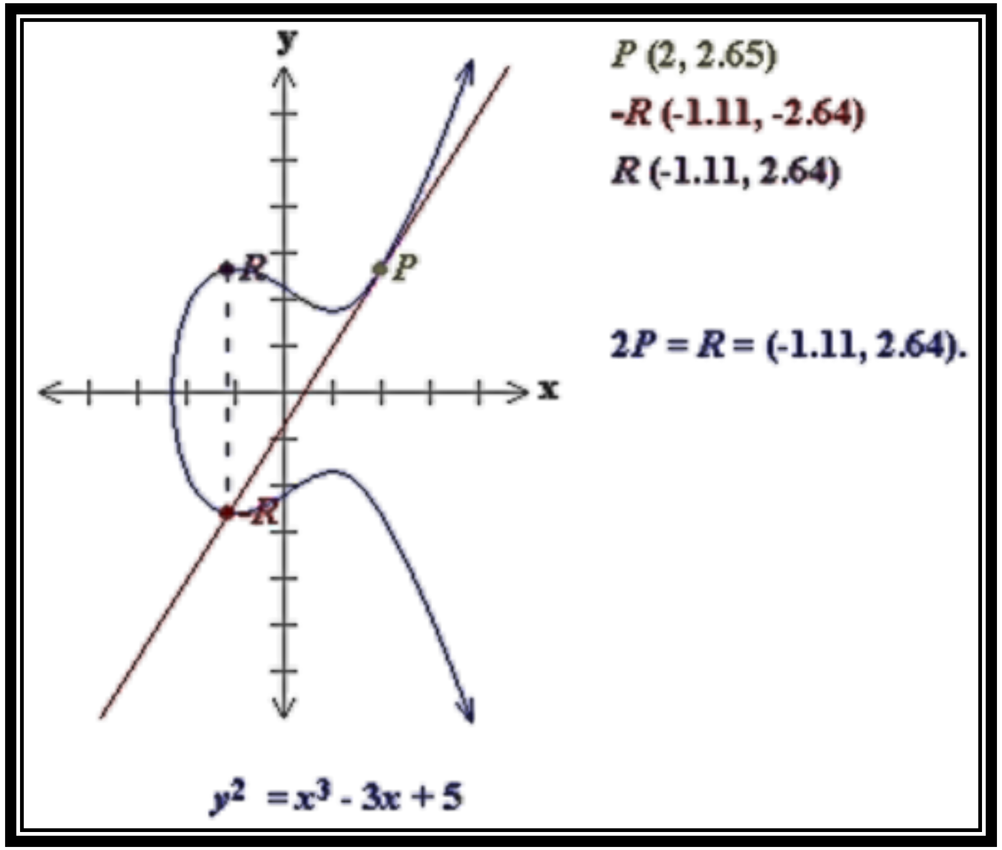


Elliptic Curve Cryptography (ECC)

- Discovered by Neal Koblitz, University of Washington, and independently by Victor Miller, IBM, in 1985
- Provides the most security per bit than any other public-key technology
- Certicom Research realized in the late 90s that ECC is a perfect cryptographic solution for wireless devices

ECC

- Meets the following constraints for wireless:
  - Battery power
  - Storage/memory
  - Computation
  - Bandwidth
- In all major security standards for wireless and constrained environments
- RIM was an early adopter of ECC and it ships in every BlackBerry produced



Wireless Security Standards

- Standards driven evolution
- Protocols, algorithms and hardware are subjected to attacks as part of the evolution
- If vulnerabilities are found, countermeasures are implemented in new revisions of standards
- Evolution of quantum computers will create additional opportunities for attack

Wireless Security Technologies

- Three are mature:

GSM
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Wi Fi

Bluetooth

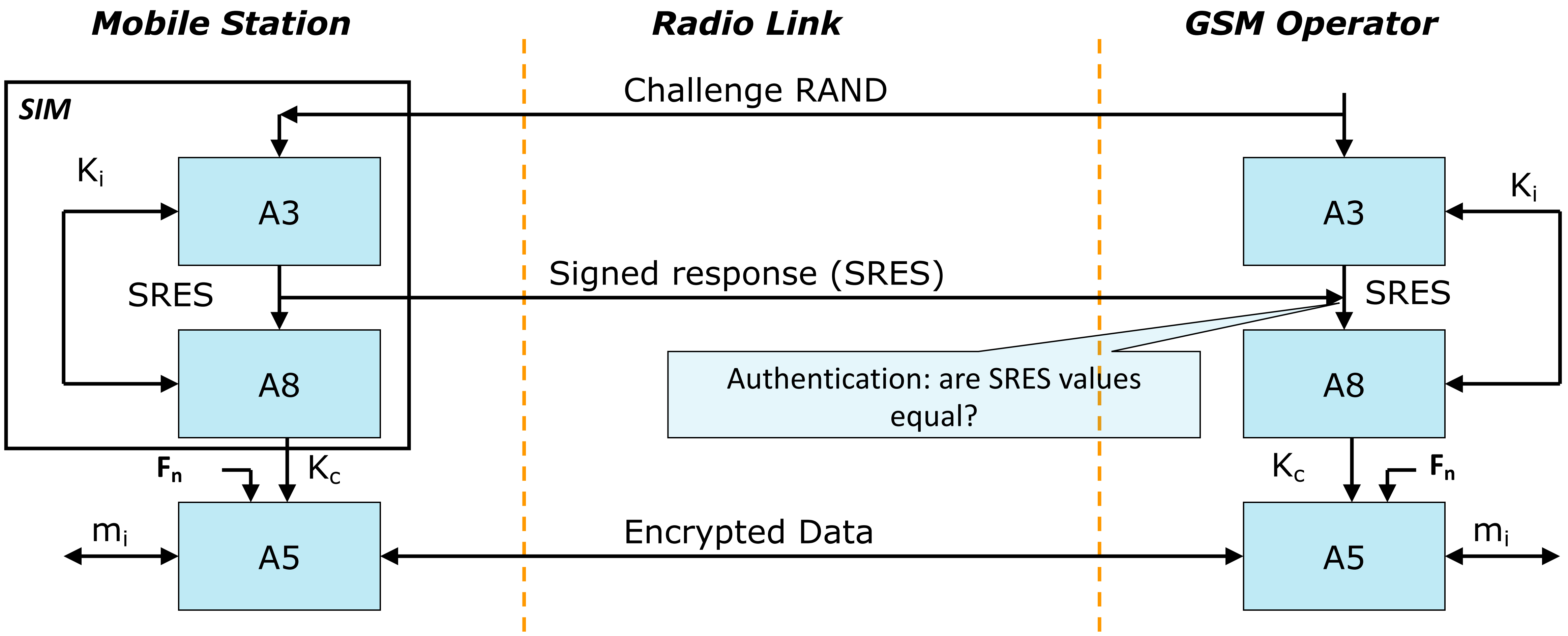
- One is relatively new:

NFC

Cellular Security Goals

- Confidentiality and anonymity on the radio path
- Strong client authentication to protect the operator against billing fraud
- Prevention of operators from compromising each others' security
  - Inadvertently
  - Competition pressure
- Driven by ETSI (http://www.etsi.org/)

Authentication and Encryption Scheme



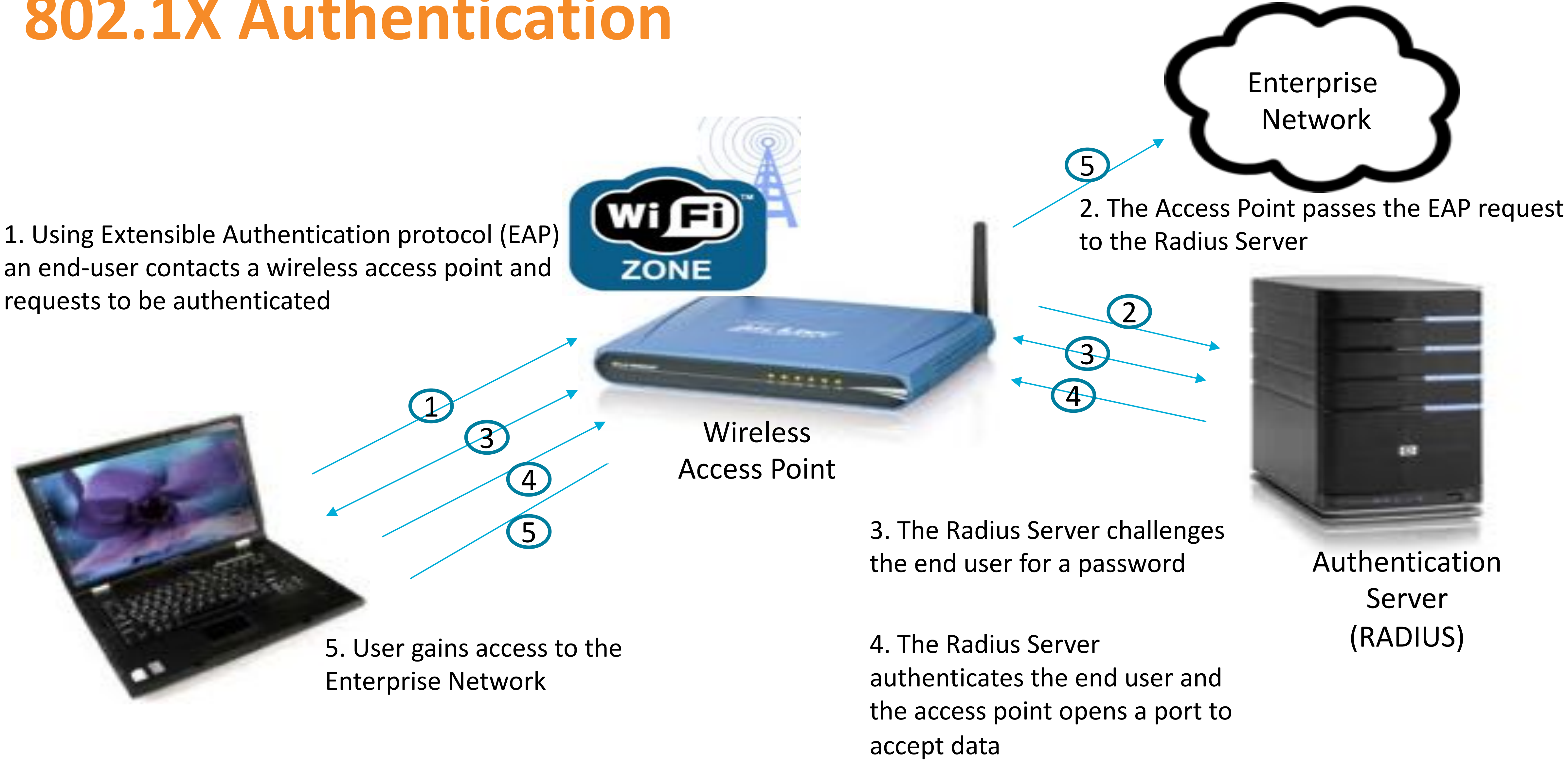
- K_i – Subscriber Authentication Key (128 bit key)
- Subscriber's SIM (owned by operator, i.e. trusted)

WiFi Security Goals

- Confidentiality on the wireless LAN
- Strong client authentication to protect the network from unauthorized use
- Standard algorithms for home and enterprise use
- Driven by IEEE 802 (http://www.ieee802.org/)

	Authentication	Encryption	Suitable for Corp WAN	Suitable for hone and small business WLAN
WEP	None	RC4	Poor	Less than good
WPA(PSK)	PSK	TKIP	Poor	Best
WPA2(PSK)	PSK	AES-CCMP	Poor	Best
WPA(full)	802.1x	TKIP	Better	Good (expensive)
WPA2(full)	802.1x	AES-CCMP	Best	Good (expensive)

802.1X Authentication



Bluetooth Security Goals

- Secure pairing of devices in a short range
- Authentication and confidentiality
  - Protect against eavesdropping and man-in-the-middle
- **Secure Simple Pairing Protocol (SSP)**
  - Unlike GSM and WiFi, Bluetooth creates a secure channel first, then authentication
- Driven by the Bluetooth SIG (http://www.bluetooth.com)

Secure Simple Pairing Protocol

Let's Pair

Public Key Exchange: Elliptic Curve Diffie-Hellman

Authentication: Numeric comparison, Just works*, Out of Band, Passkey Entry

Verification: Verify that key exchange succeeded

Link key calculation: Derive link key for communications

Secure link established

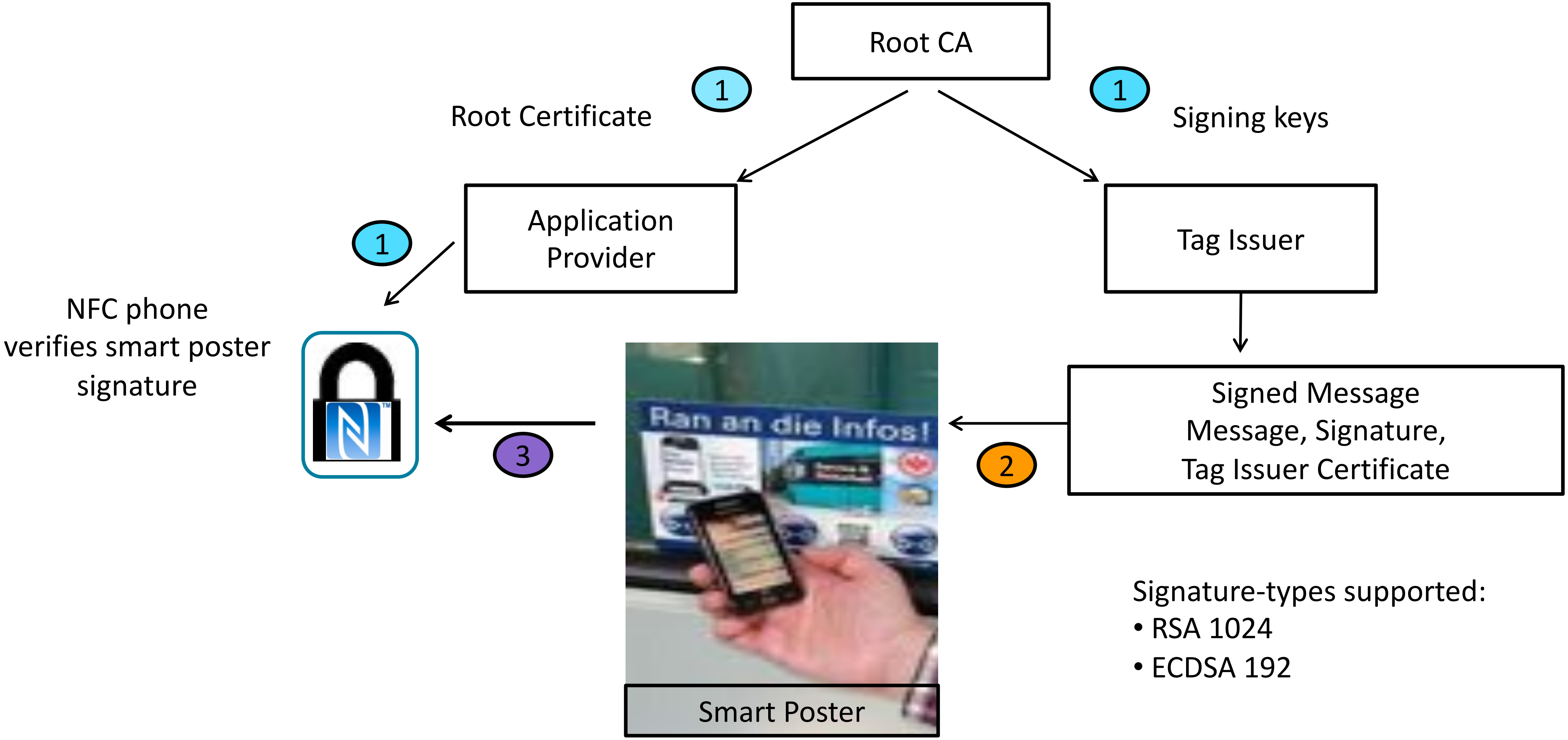
* Just works only protects against passive man-in-the-middle

NFC Security Goals

- Protect authenticity and integrity of messages sent and received using **digital signatures**
  - No explicit goal for confidentiality
  - Hand-off to Bluetooth or WiFi
- Driven by **NFC Forum** (www.nfc-forum.org)

Objects sending/receiving radio signals

NFC Smart Poster



Signature-types supported:

- RSA 1024
- ECDSA 192

Dialogue

1. **If you were an enterprise user/customer, how would you view the wireless industry's roadmap?**
   - What impact would long-term evolution have on your business objectives?
   - As a user?; As IT management?
2. **If you were an IT manager, what concerns would you have about wireless evolution/disruption over the next 10 years?**
   - Most optimistic picture of the next 10 years?; Most pessimistic picture?

Evolution toward 5G

Let’s start with wireless capacity

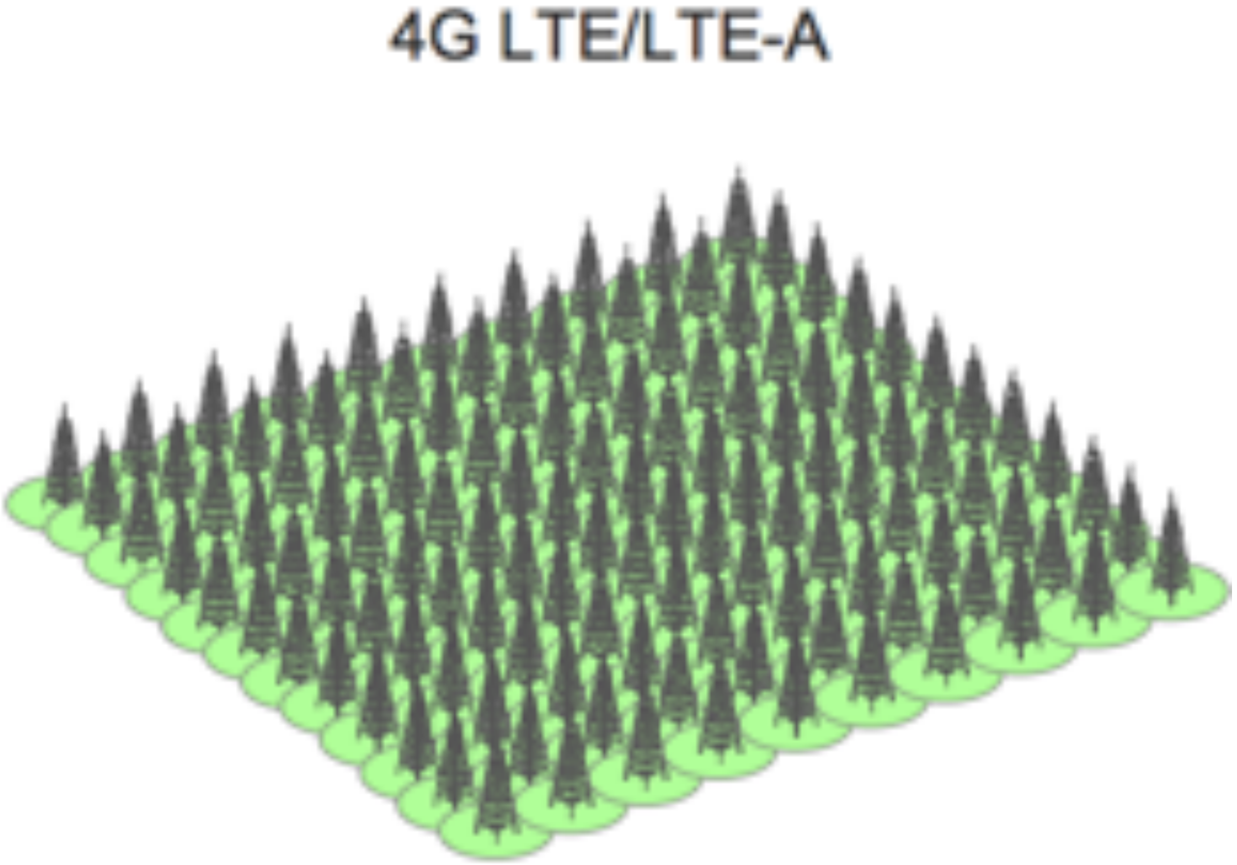
- Wireless capacity increased approximately 1,000,000 times between 1957 and 2007 : 50 year timespan
- Breaking down these gains shows

25x information theoretic improvement (modulation, coding)

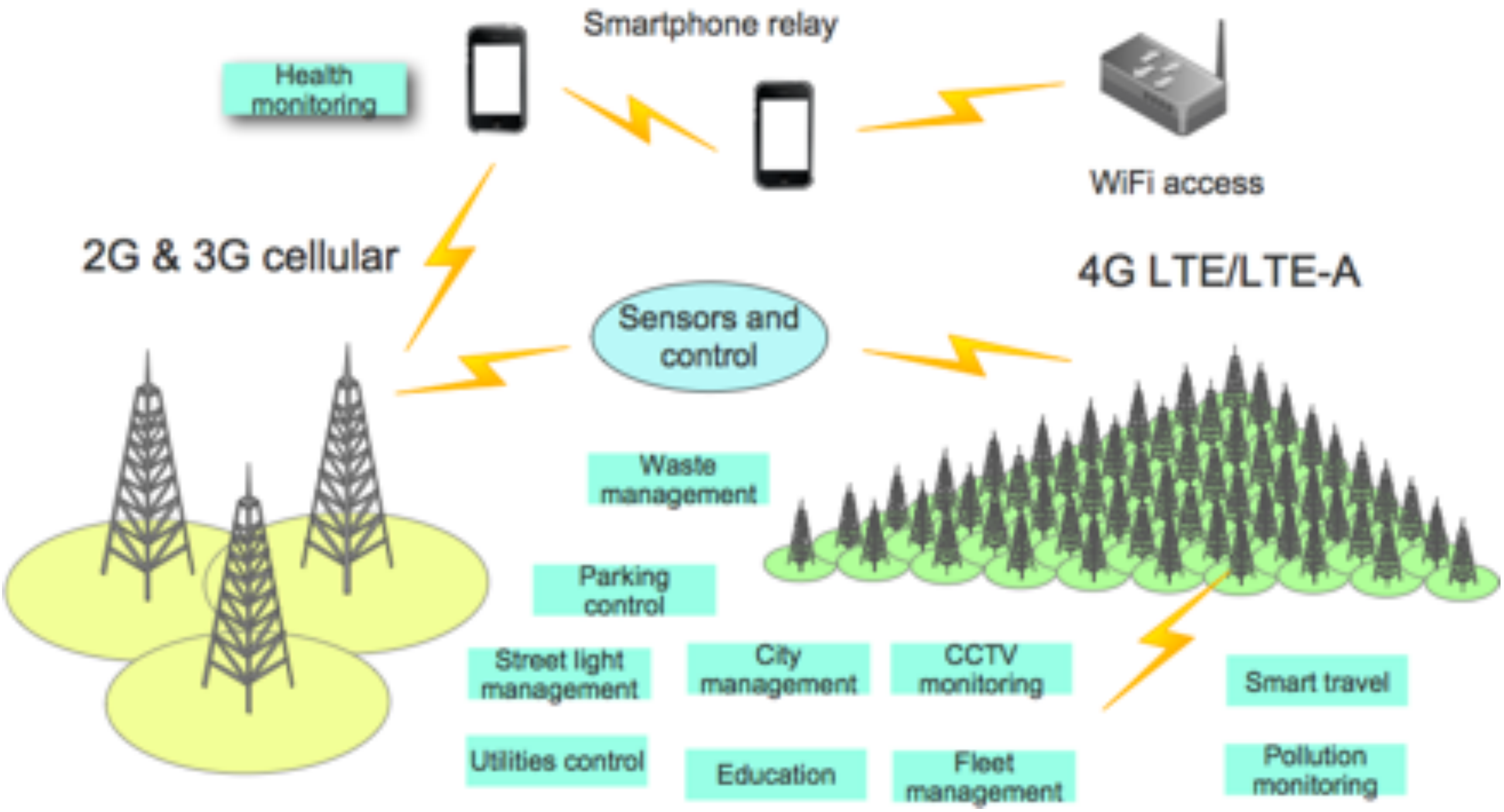
1600x gain by reducing cell sizes and transmit distance

25x statistical improvement (wider contiguous spectrum)

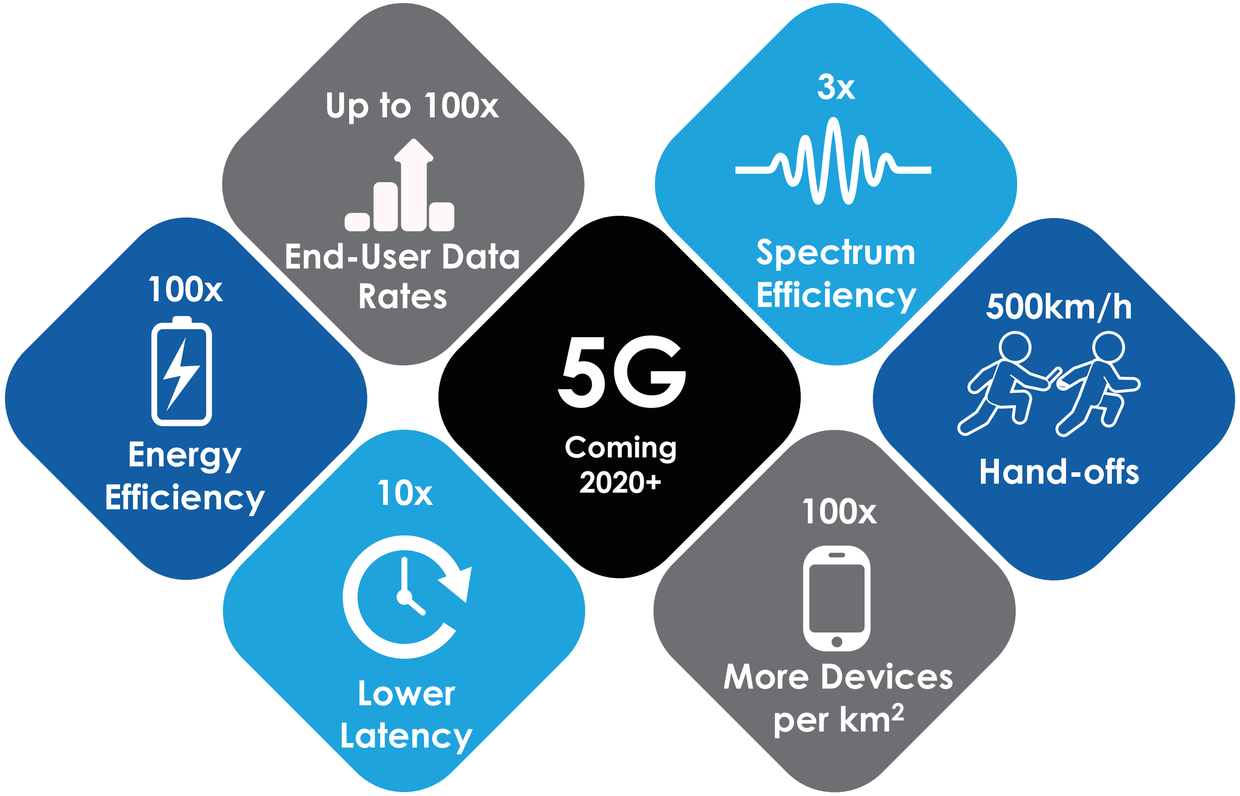
Evolution from coverage to capacity planning



5G evolution: ubiquity of wireless access?



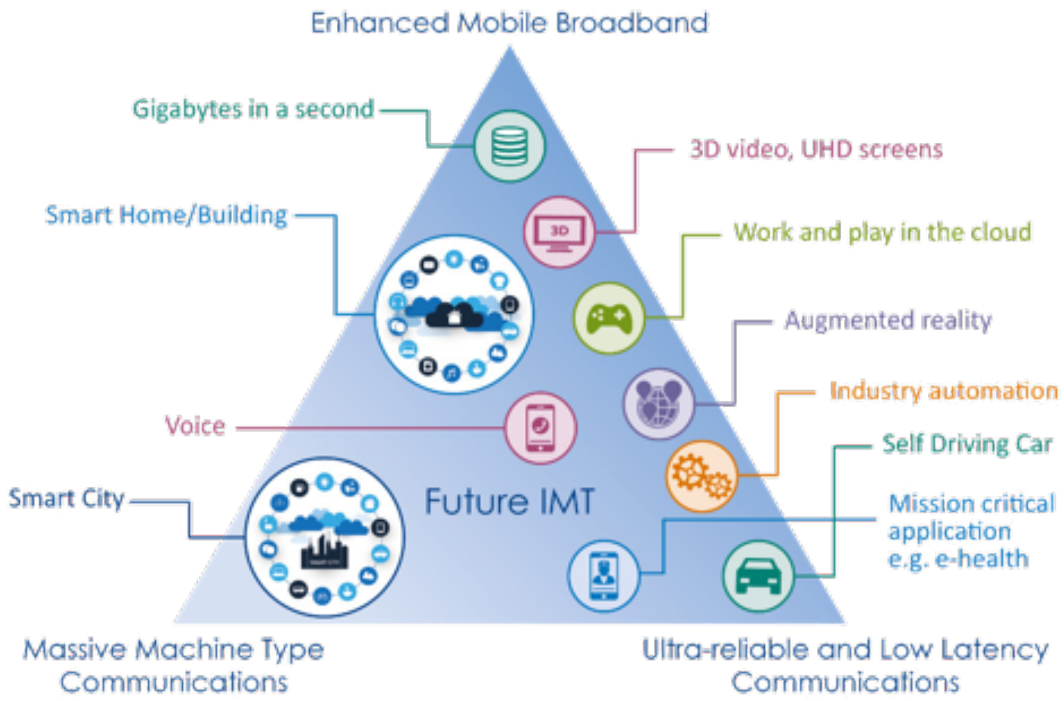
Comparing 4G and 5G Requirements

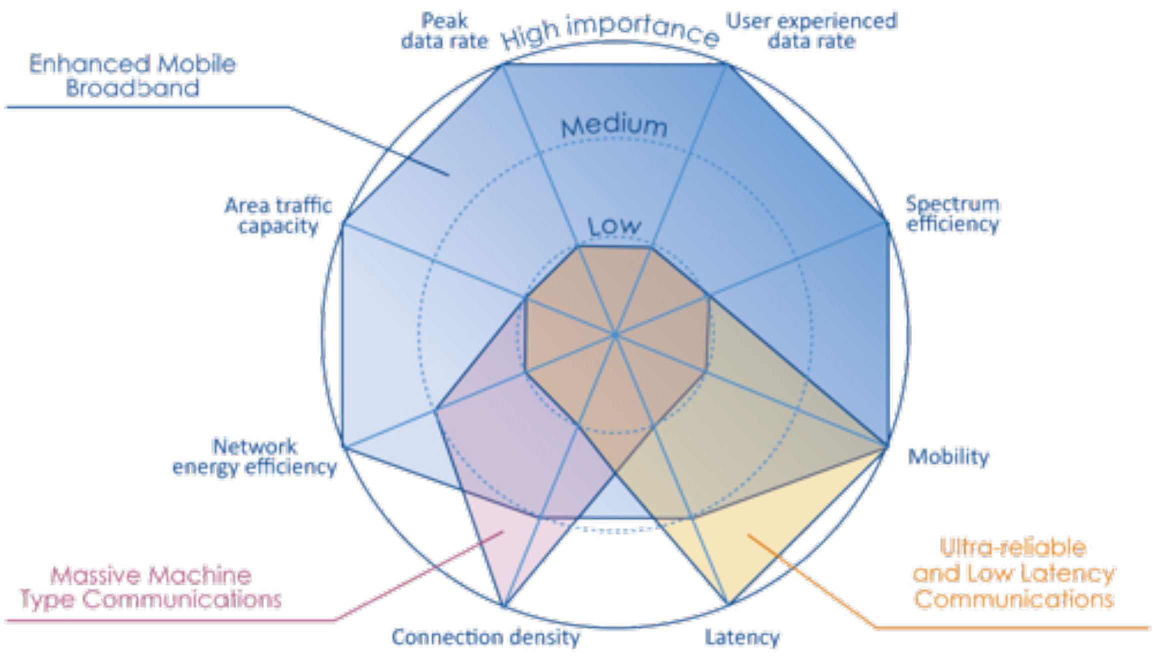


Enabled by New Technologies:

- Network Slicing
- Service Based Architecture (SBA)
- Network Function Virtualization (NFV)
- Massive MIMO + beamforming with small cells
- Millimeter Wave Transmission (mWT)
- Multiple access Edge Computing (MEC)
- Control Plane & User Plane Separation

5G Sample Use Cases





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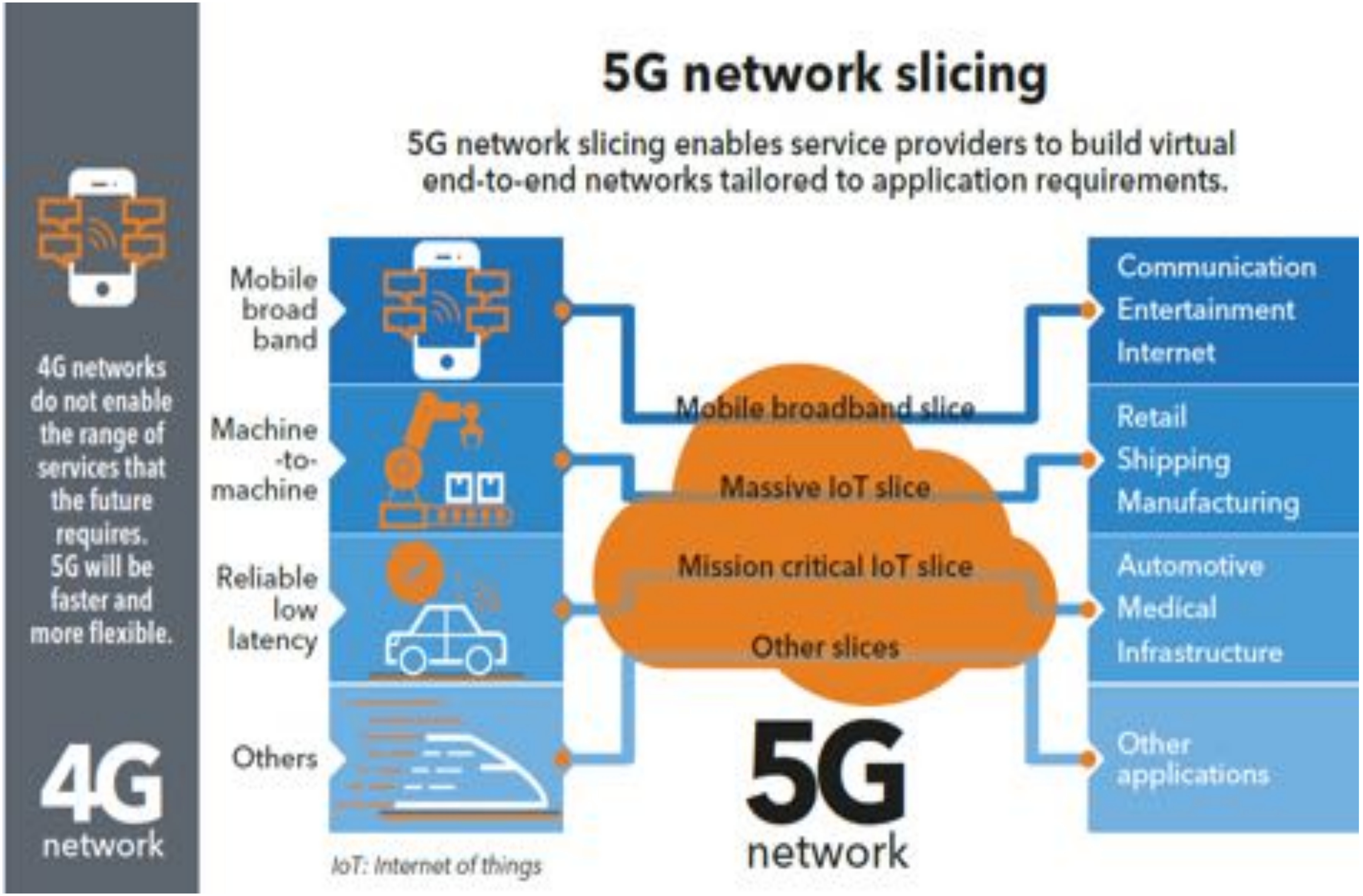
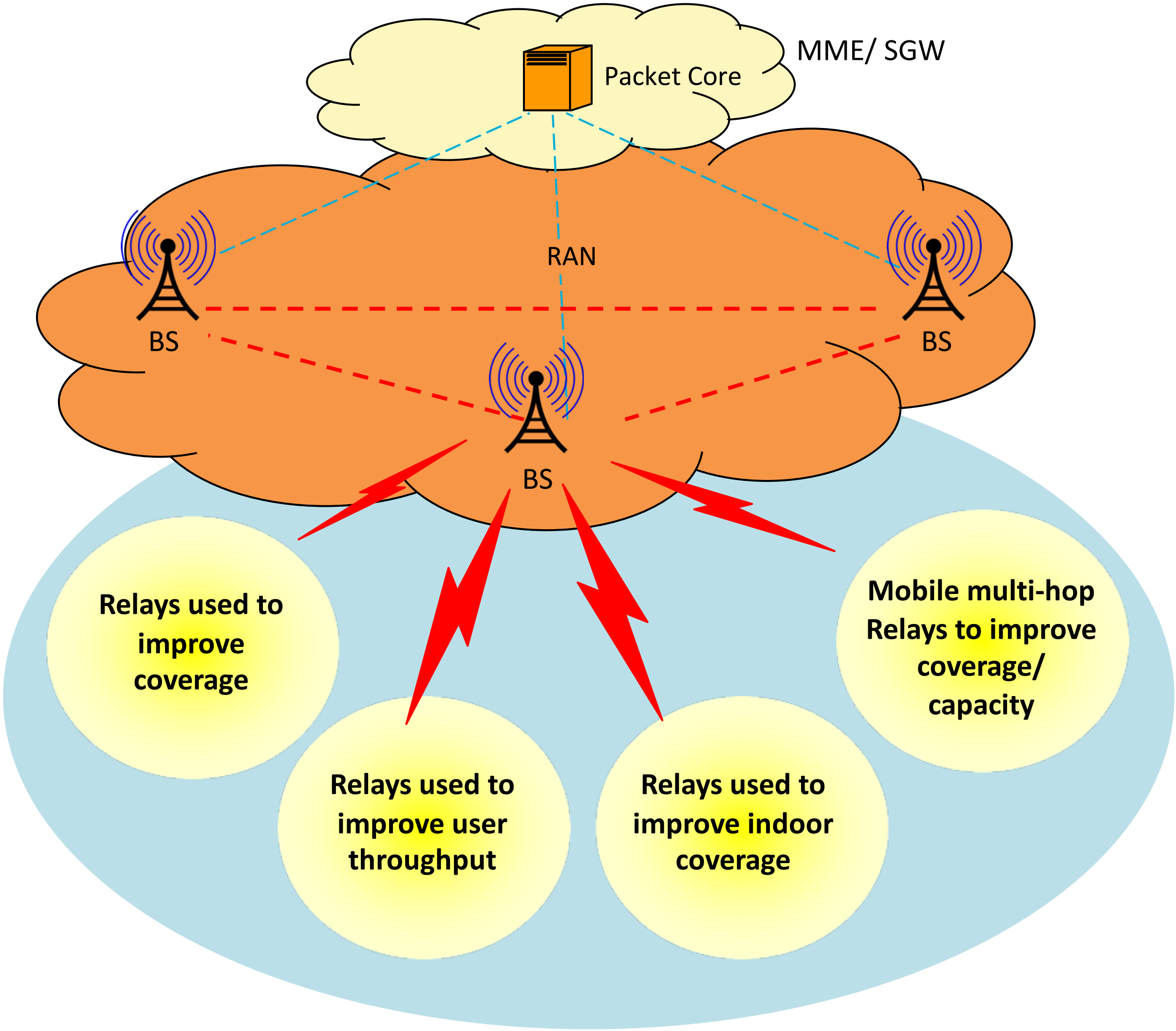


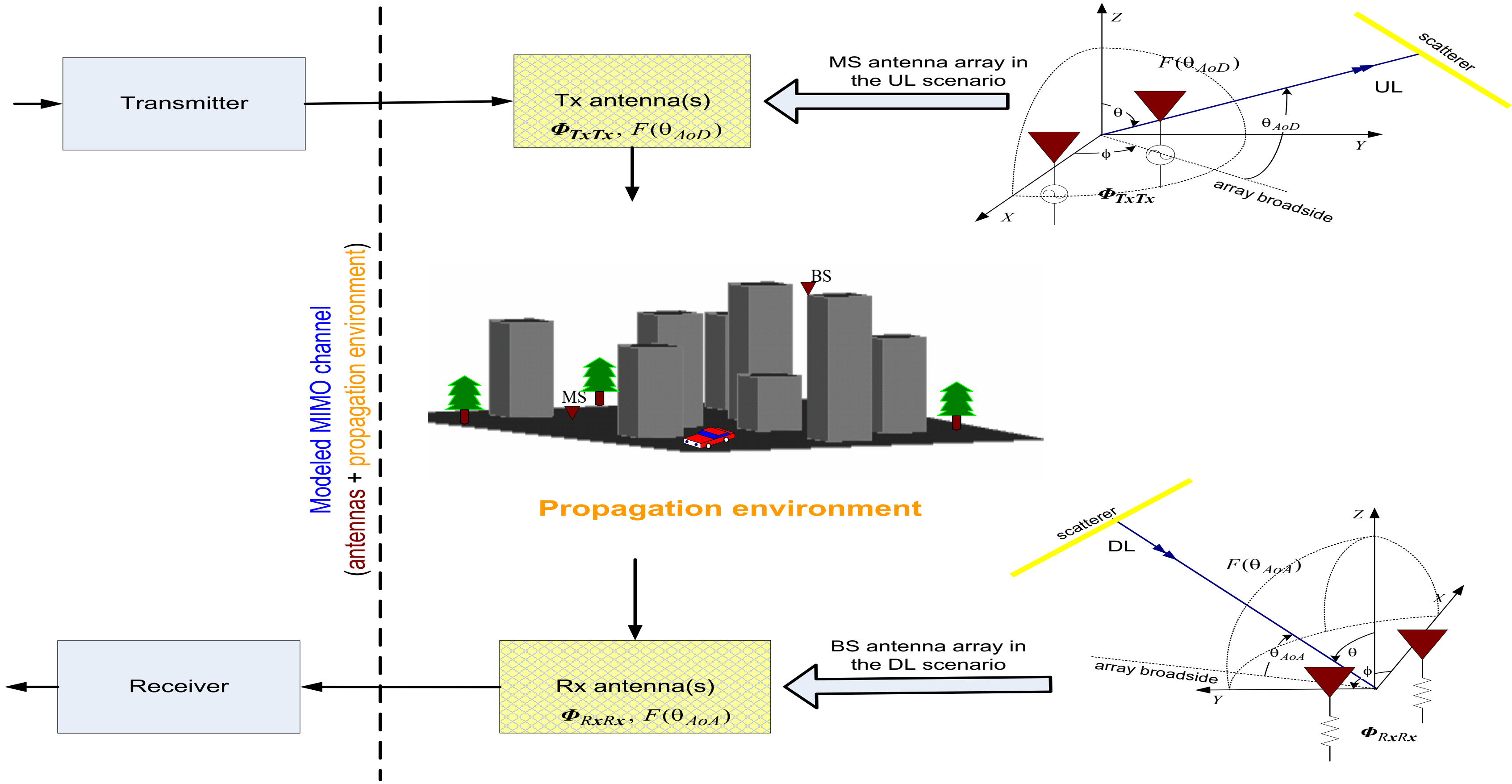
Source: https://news.itu.int/why-end-to-end-network-slicing-will-be-important-for-5g/

Advanced Relays – Increase Coverage/Capacity



- Target coverage with Macro base stations for initial deployments
- Relay stations added for incremental capacity growth, richer user experience and coverage extension

Part of the Challenge: Wireless Environment



- accurately model the antennas using electromagnetic approaches
- accurately model the environment using propagation channels
- incorporate both MIMO channel components in the final model

More advances on MIMO and Variations

Benefits

- Outages reduced using information from multiple antennas/paths
- Higher data rate and system capacity
- Better signal quality (BER)
- Increased coverage

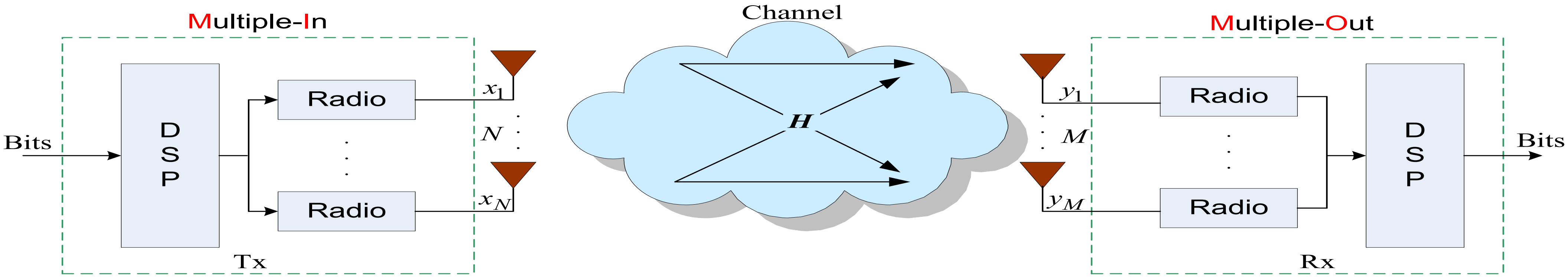
Challenges

- Processing complexity/cost
- Best performance requires rich multi-path environment
- Device constraints (number of antennas, spacing, number of RF chains, coupling, etc.)
- Network to support the technology

Variations

- Beam-forming MIMO
- Phase coherency among antennas
- Use of conversion theorem to electrically steer signal – aim signal at desired station rejecting interferers
- Extension of existing standards
- Spatial-multiplexing MIMO
- Allows for multiple users by transmitting parallel data streams at the same time using spatial coding technique
- Requires new standards (changes the format of the signal)

New Standards like LTE-Advanced and Beyond



- Multiple Input – Multiple Output (MIMO)
- Symbols are interleaved between transmitters
- Multiple signals are transmitted at the same time and frequency
- A linear combination of the transmitted signals are received

$$\boldsymbol{y}(t) = \boldsymbol{H}(t)\boldsymbol{x}(t) + \boldsymbol{n}(t)$$

For a full-rank fixed *N* × *M* AWGN channel, the channel capacity is:

$$C = \min(N, M)\log_2\left[1 + \frac{\rho}{\min(N, M)}\right] \quad \text{bits/s/Hz}$$

Where: $\rho = \frac{E_b}{N_0}$ for the noise-limited case

Capacity is increased over the single antenna solution under certain conditions, but not all.

Multi-user MIMO with Beam-forming

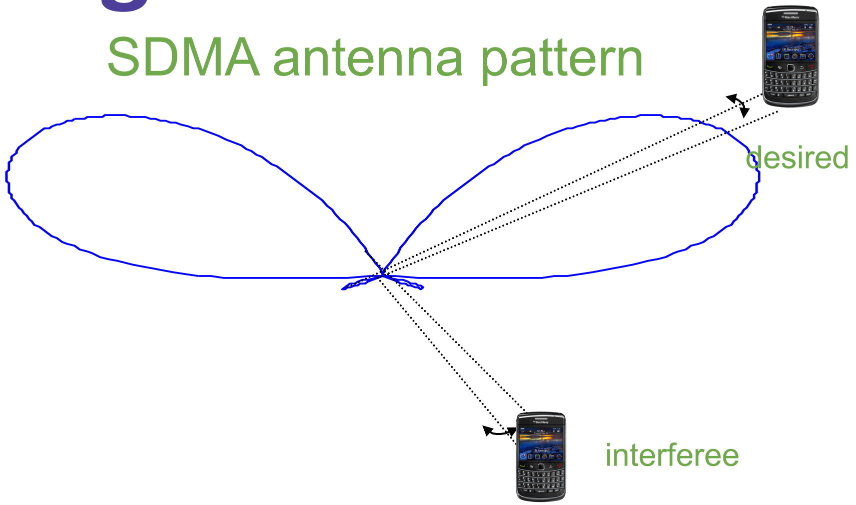
SDMA (Space Division Multiple Access)

- Uses closely spaced, co-polarized antennas
- Angle spread << than beams
- Works best in lower angle spread environments
- Antenna patterns change slowly
- Low feedback and channel estimation requirements
- Designed for 1 layer (non-MIMO) transmission

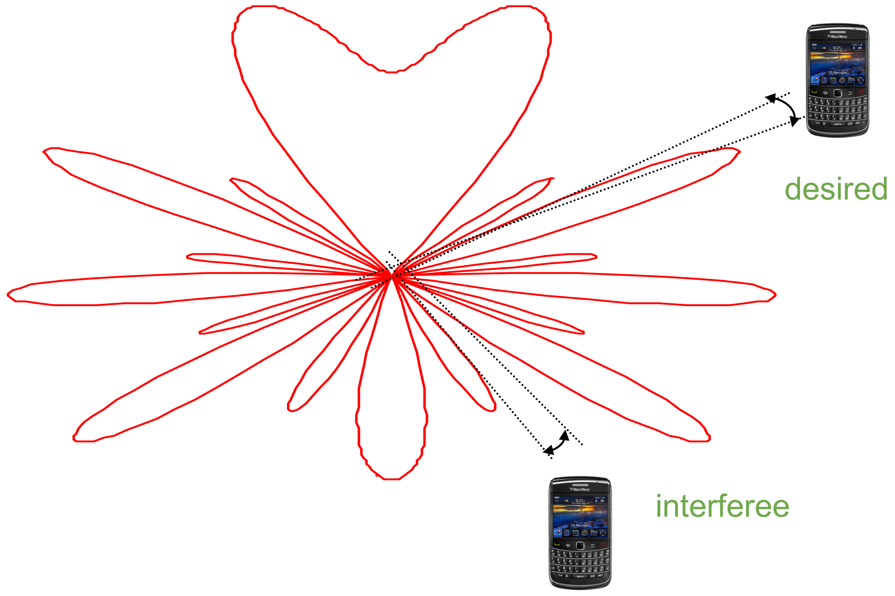
MU-MIMO (Multi-User Multi-Input Multi-Output)

- Uses diversity antennas
- Angle spread not << than beams (grating lobes)
- Works well in high angle spread environments
- Antenna patterns change quickly
- Higher feedback and channel estimation requirements
- Compatible with Single User MIMO (SU-MIMO)

SDMA antenna pattern

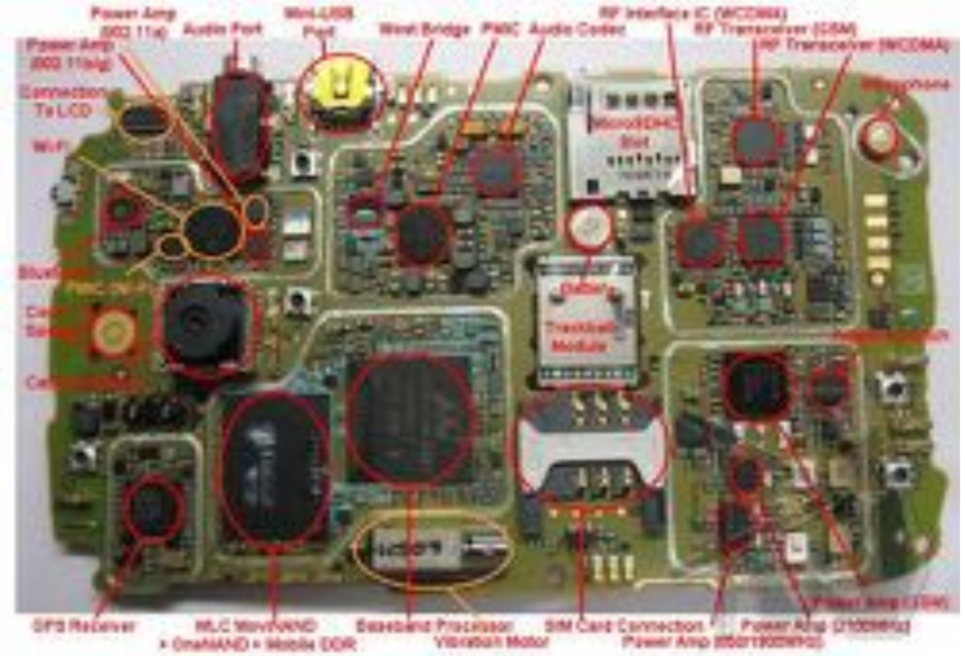


MU-MIMO antenna pattern

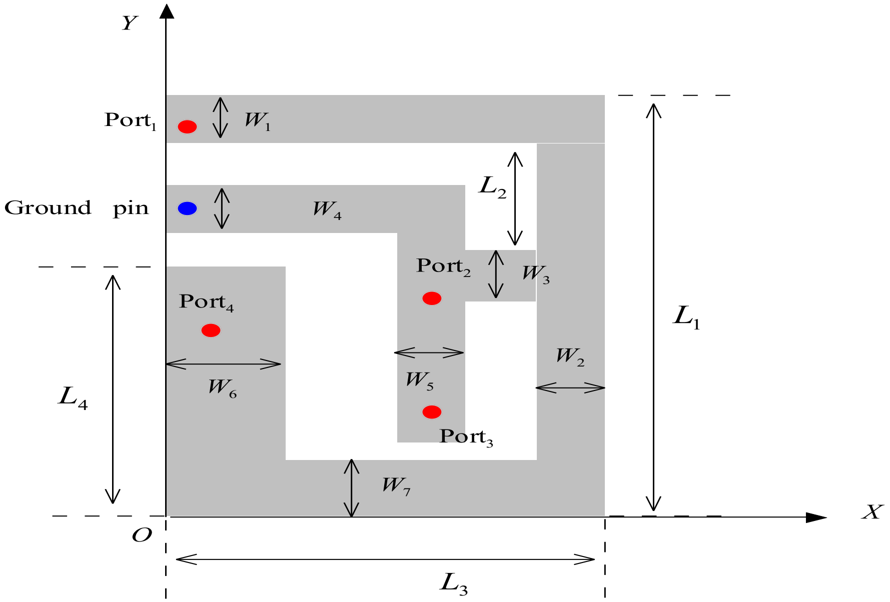


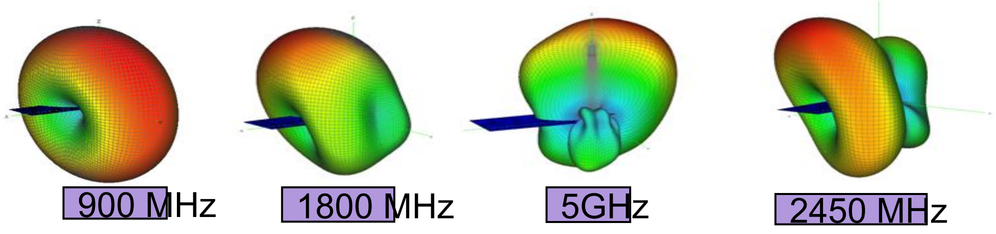
Practicality Issue

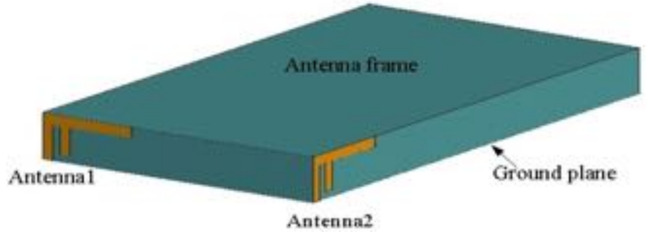
- Antennas take up space
- Performance gains small
- Which features would you like to give up?



More wireless spectrum from ITU?
Multiband Antennas and tuneable systems



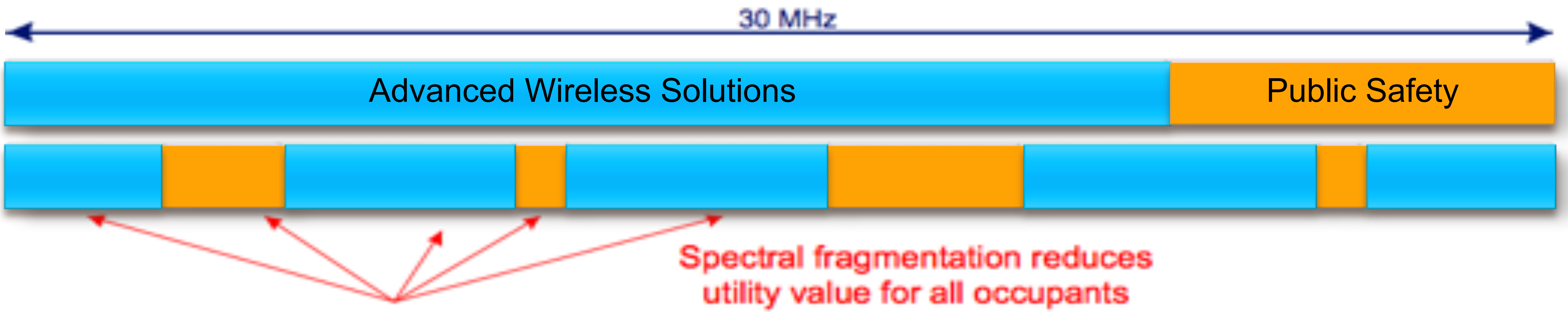




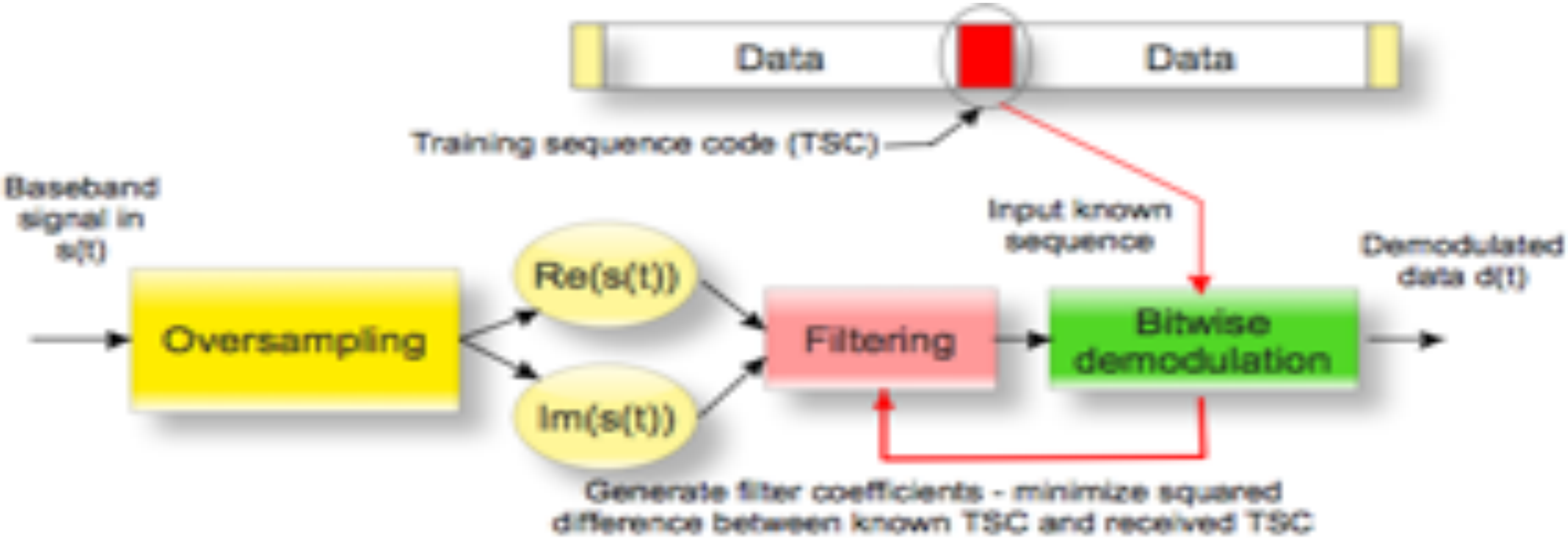
Tuneable systems adapt dynamically to head, head and hand and hands only operation

Frequency Spectrum Challenges - Regulatory

- **OFDM** - greater trunking efficiency if occupied spectrum is more than 10 MHz
- What if the operator doesn't own a 20 MHz segment of usable, contiguous spectrum?
- Future trend - broader spectrum occupation for higher data rates and more trunking efficiency
- Regulators need to give proper attention to the complexities of allocating contiguous spectrum as wireless technology evolves



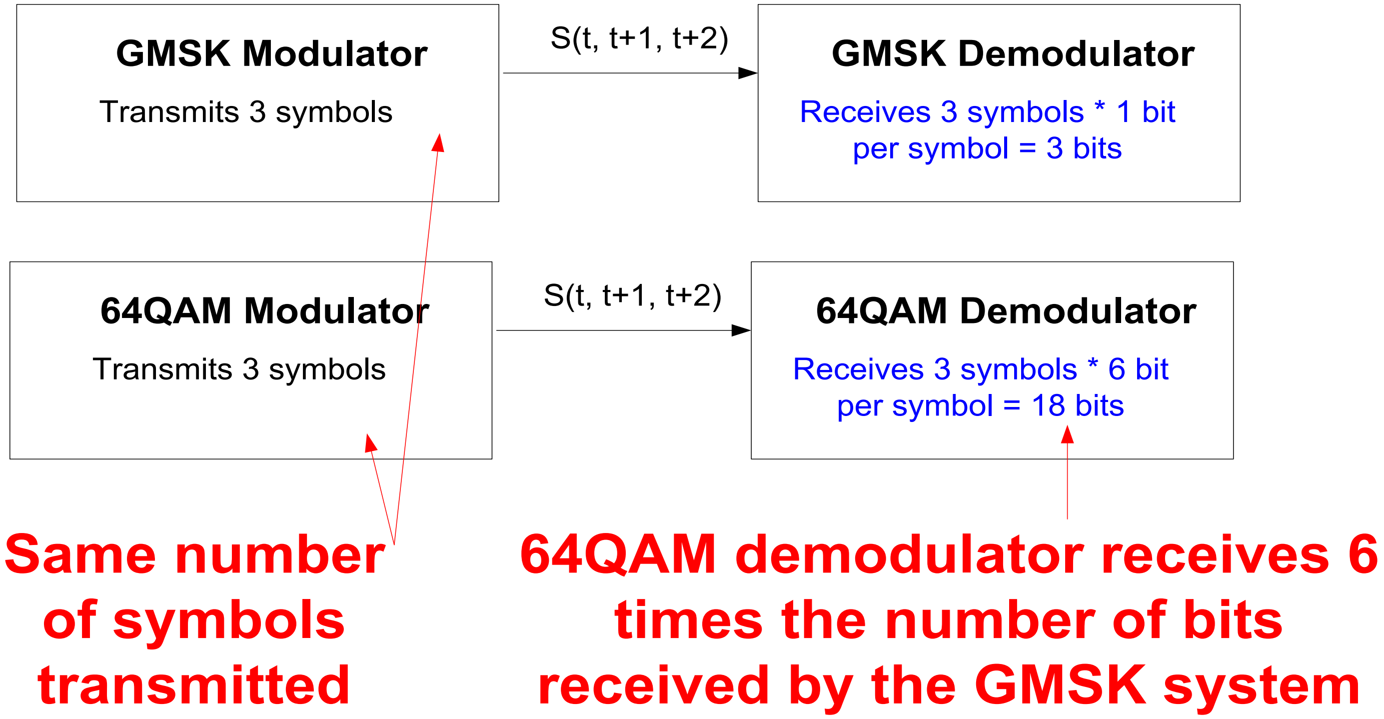
Advanced Receivers & interference cancellation



Increase radio link capacity by increasing tolerance to co-channel interference

Higher-order modulation

Look for higher-order modulation techniques in the coming years



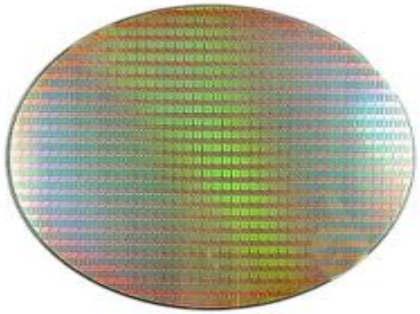
Why?

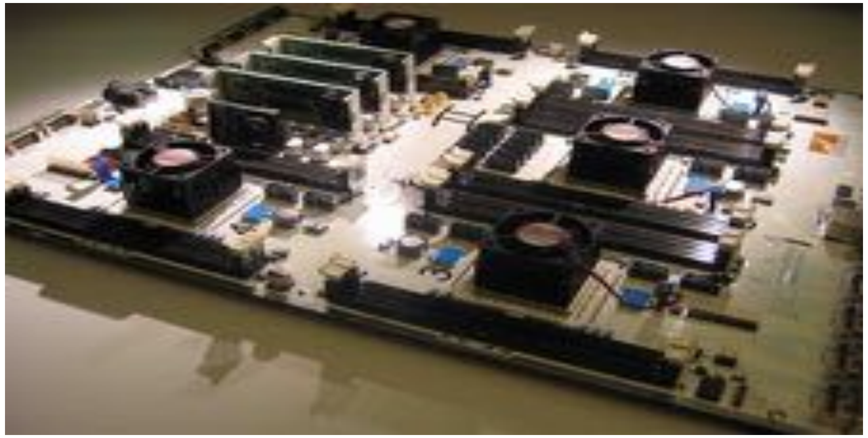
- More processing power available every year
- Steady improvements in equalizer technology

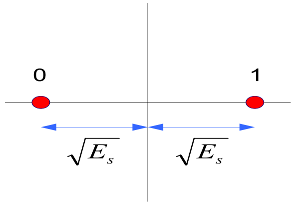
More bits per symbol

- More information available per symbol transmitted means…
- Faster data rates
- Greater system capacity
- Take advantage of local signal quality maxima

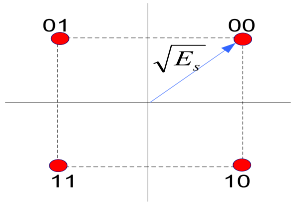
More Bits Per Symbol



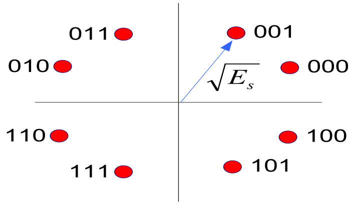




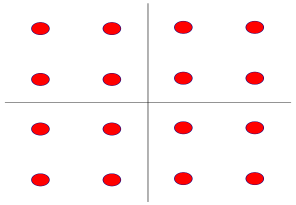
Bi-phase modulation: 1 bit/symbol



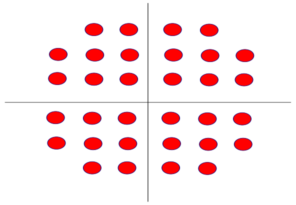
Quadrature phase shift keying (QPSK): 2 bits/symbol



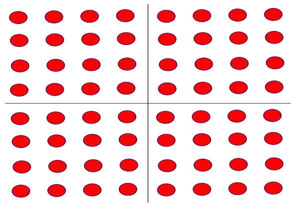
8-level phase shift keying (8PSK): 3 bits/symbol



16 Quadature amplitude modulation (16QAM) modulation: 4 bits/symbol



32 Quadature amplitude modulation (32QAM) modulation: 5 bits/symbol



64 Quadature amplitude modulation (64QAM) modulation: 6 bits/symbol

Higher data rates require higher S/N ratio

Shannon's Theorem

States that the maximum number of bits/symbol we can support is limited by i) bandwidth and ii) signal quality

Channel capacity, i.e. max number of bits/symbol

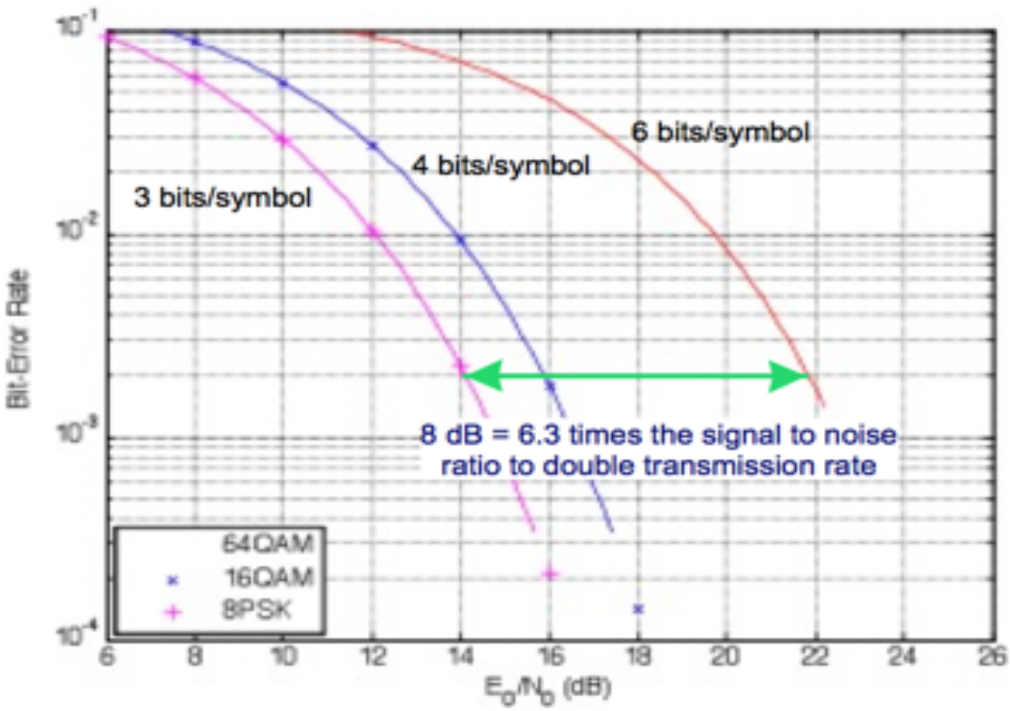
$$C = B\log_2\left(1+\frac{S}{N}\right)$$

How much bandwidth do we occupy?

What is the quality of our signal?

C = capacity in bits/symbol
B = Bandwidth occupied by signal (Hz)
S = Signal strength (W)
N = Noise level (W) = kTb = thermal noise floor

Doubling the speed requires more than 6X the power



Advanced Navigation Technology

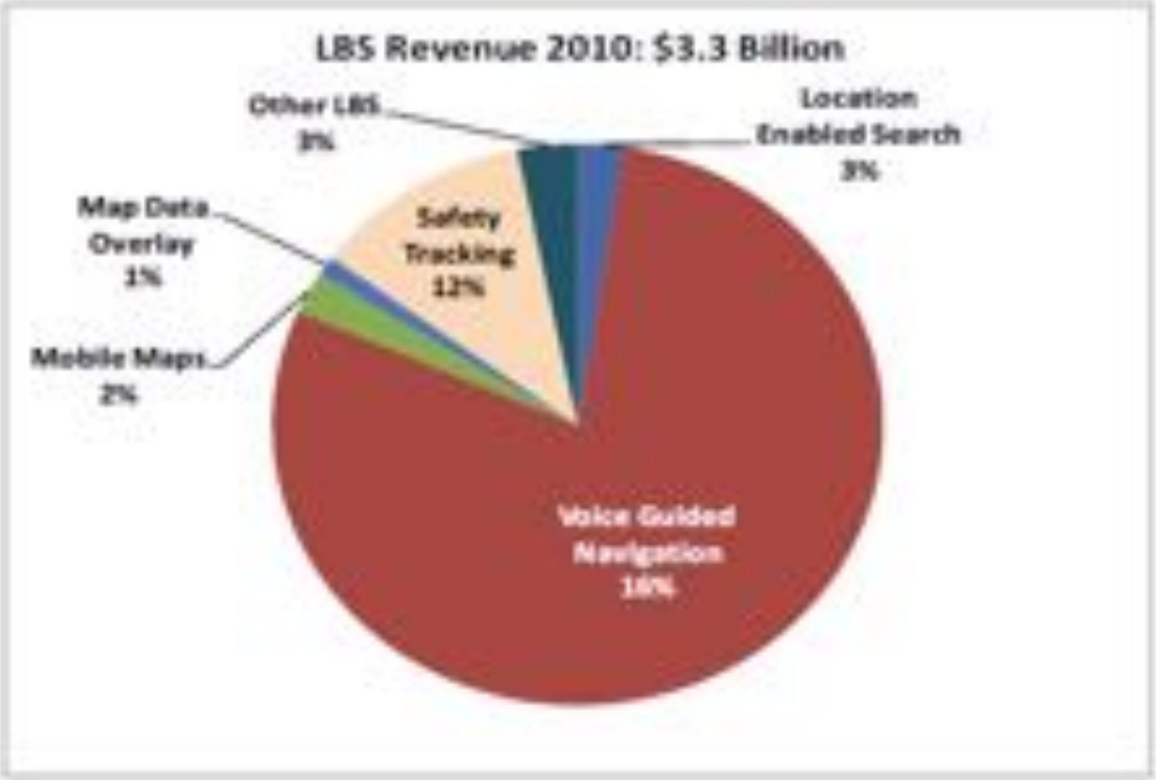
- Privacy issues for location based services
- Privacy and security architectures
- GPS add-ons for in-building location
- GDPR regulations in Europe!

Location Based Search growing faster than others

Source: Strategy Analytics, Geography: North America

* *All mobile search users, not only location enabled search users.*

Indoor location and navigation will be important



Source: Strategy
Analytics, Geography:
North America

Location Enabled Search (including indoor):
~ 0.1 billion -> ~ 5 billion

mHealth

Short-range wireless

The cornerstone of mHealth and certain remote sensor applications

New gigabit wireless 802.11ad on 60 GHz

Sensor Networks

eCommerce

eCommerce is fairly well adopted today, but lacking in mobile innovation

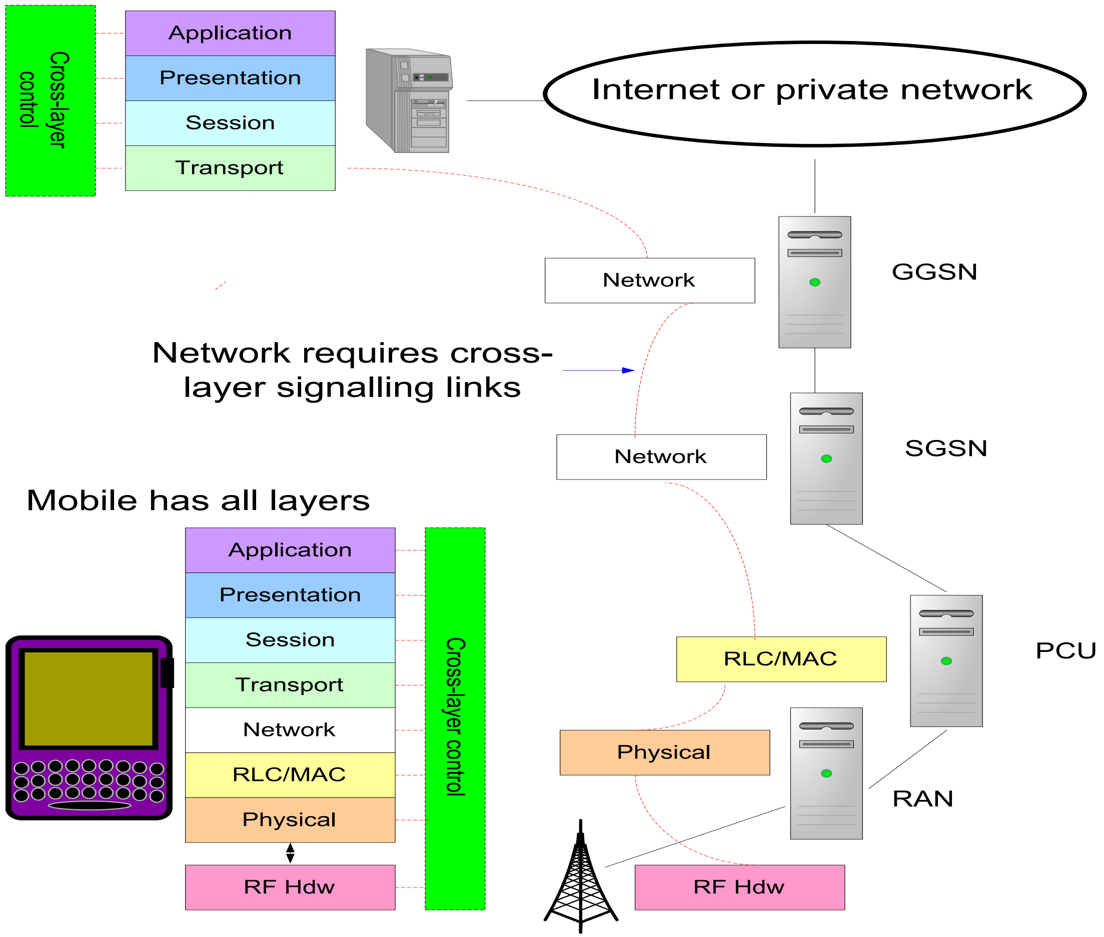
Near-field communication (NFC)

Prototype NFC posters and small scale payment systems have been demonstrated in Europe

Slow adoption thus far…

Problem: lack of Certificate Authority!

Cross-layer Design – Inter-layer Communication



- Cross-layer design used to be considered a "protocol violation"
- Cross-layer communication is much simpler within the mobile, which supports all layers
- In the network, signaling must be devised, as the layers may not reside in the same city as one another
- Permits inter-layer optimization and end-to-end Quality-of-Service (QoS) control
- Lots of theoretical studies since 2001, but lack of very practical progress!

Software Defined Radio Systems

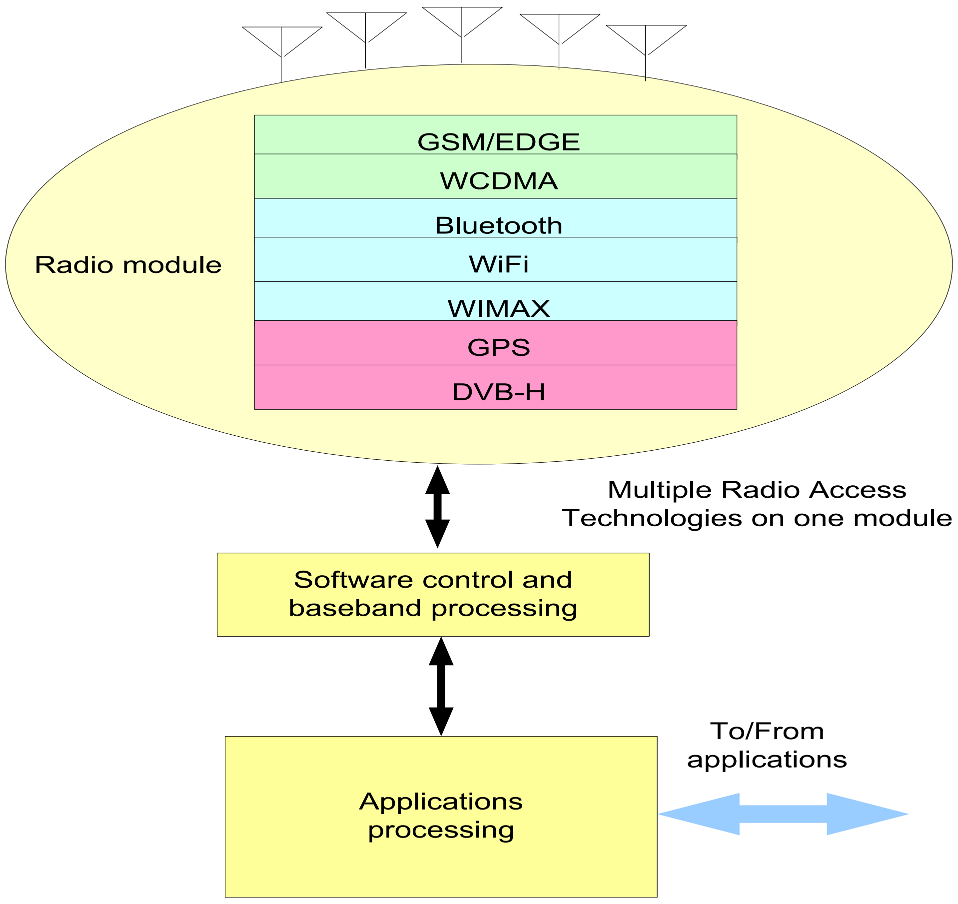
Industry and academia have many definitions for SDR:

- flexible radio subsystem in which software controls the selection of a finite set of pre-determined bands and modes
- ultimate SDR is a "Universal radio frequency Turing machine" that would generate and detect any arbitrary waveform unlimitedly over the entire electromagnetic spectrum
- SDR forum specifies degrees of "software definability" that describe flexibility somewhere between these extremes

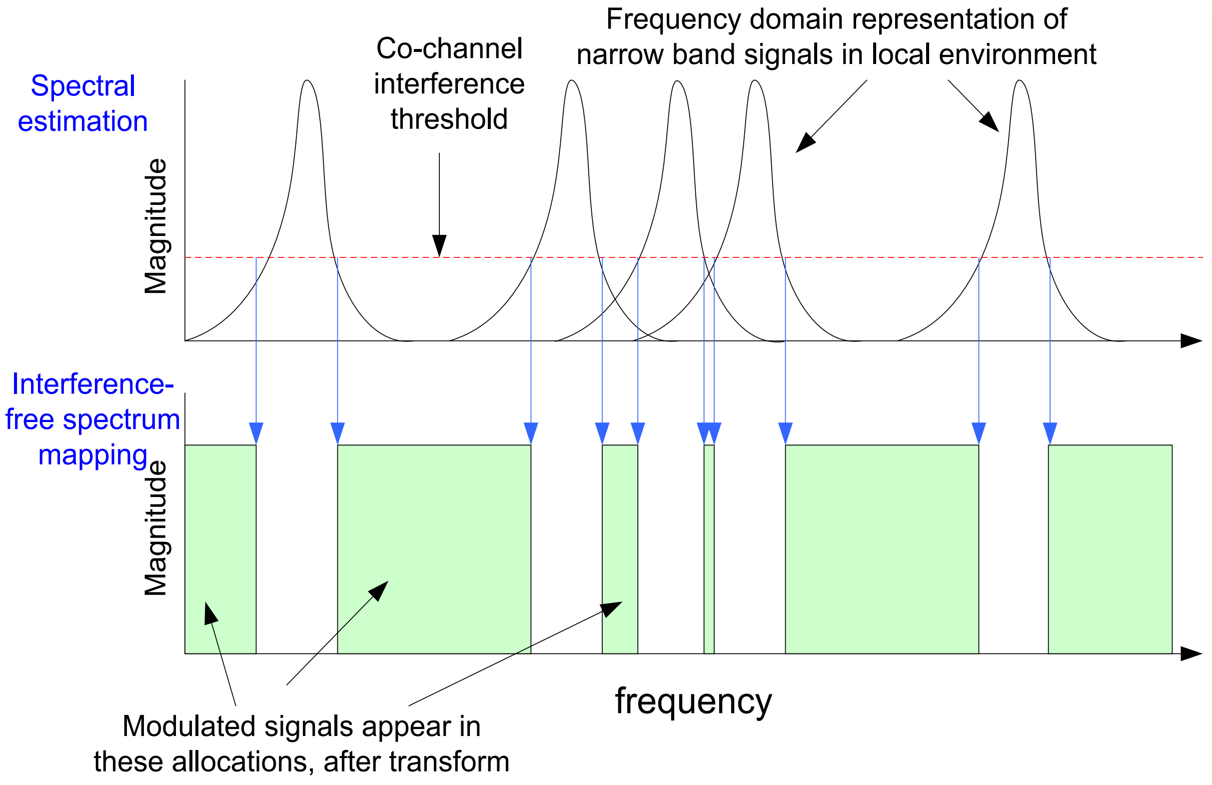
Principal SDR characteristic: migration of intelligence closer to the radio hardware

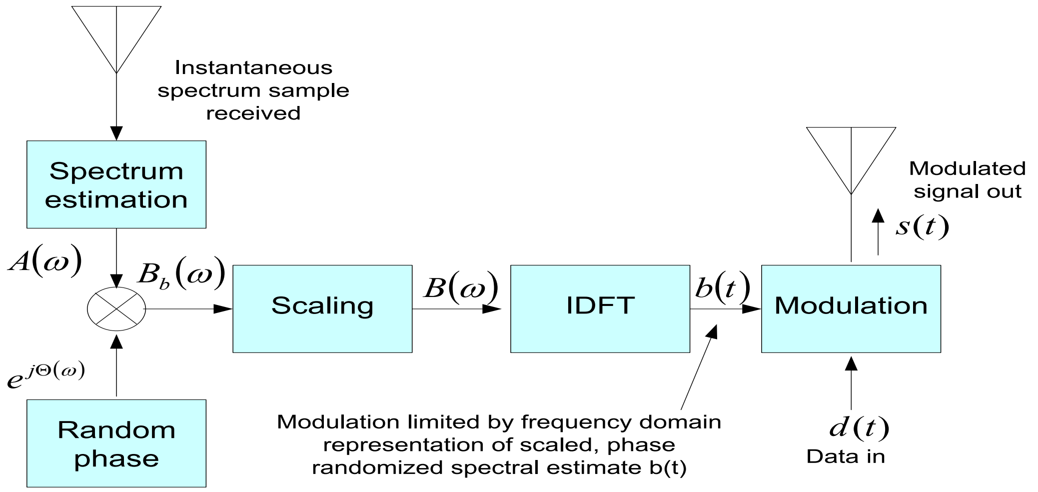
Fundamental SDR concept: flexibility

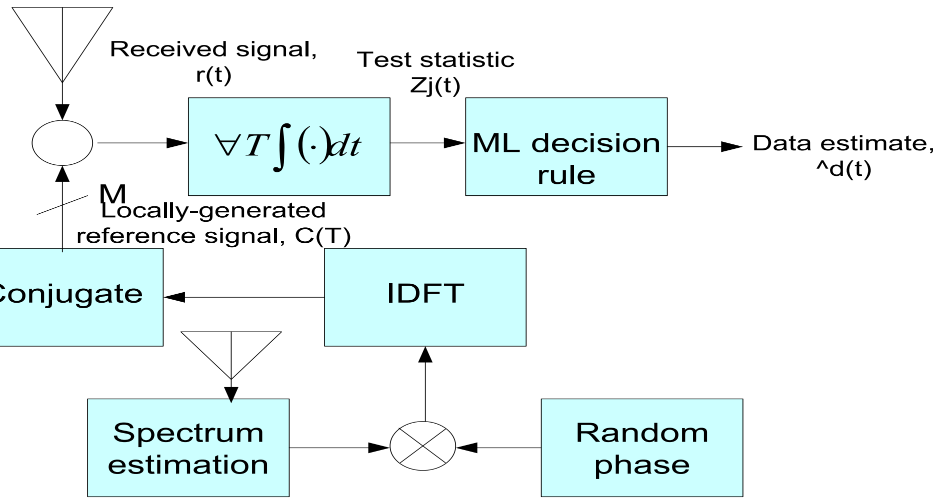
Software defined architecture



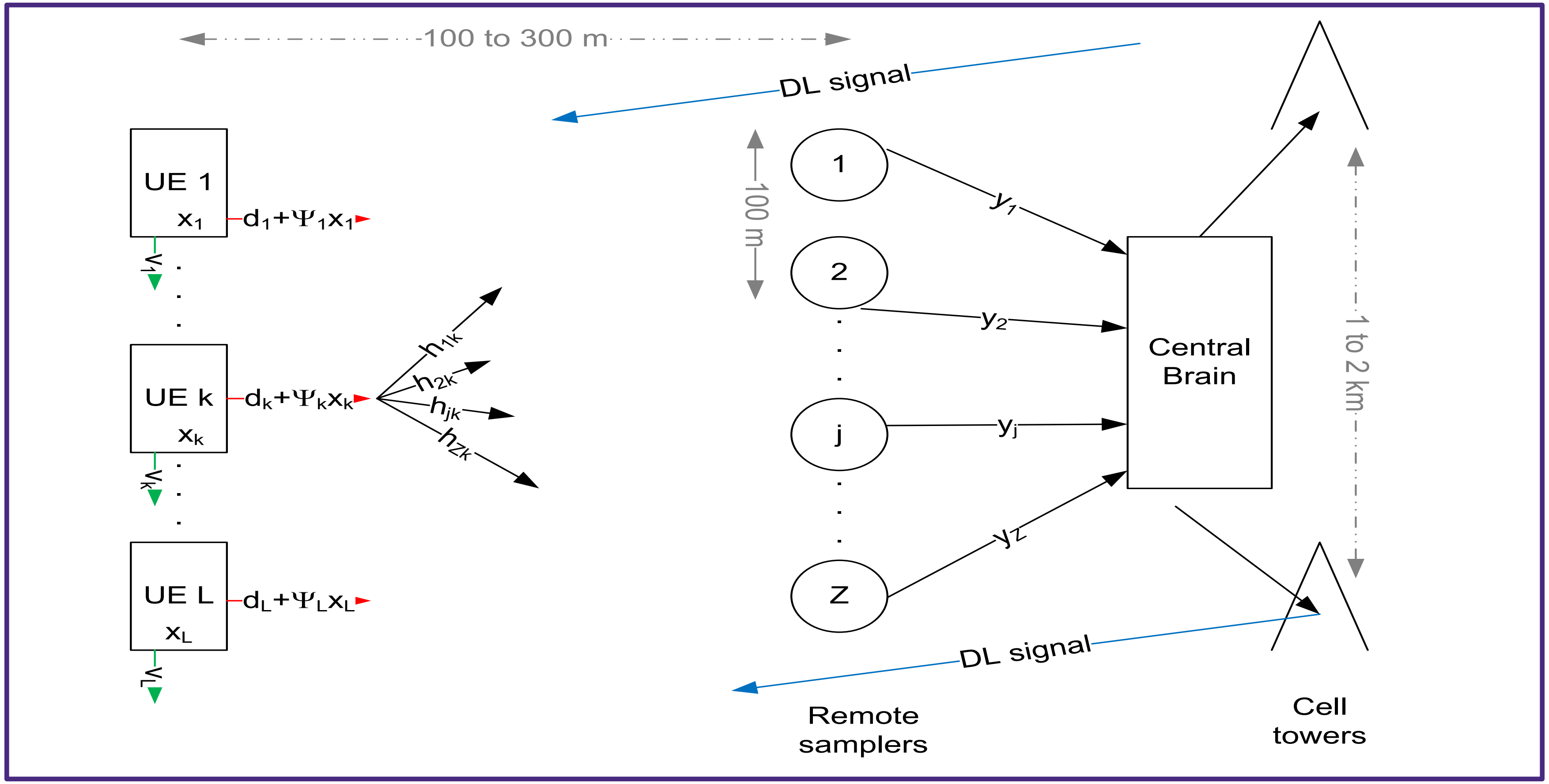
Cognitive and Flexible Radio Systems







Remote Sampler – Central Brain Topology



A high density of mobile stations can be supported by deploying a dense fabric of inexpensive remote samplers.

Telematics, Automated Logistics

Connected and self-driving cars

Automated fleet scheduling

Automated shipping/package routing

Huge source of new “things” to add to the Internet of Things

Properties of the 5G Network

Resilience

- Service Based Architecture
- Network Slicing
- Cross-layer security
- Software virtualization
- Redundancy mechanisms for failures, re-routing, etc.
- QoS enforcement

Identity Management

- Encrypted subscriber identities
- Ultra high precision geolocation
- Robust and flexible authentication framework
- Detection of malicious base stations

Security & Privacy

- Signalling and user traffic are encrypted and integrity protected
- Mutual authentication between UE and Network
- DDoS detection and mitigation
- Logical separation of network tenants
- Audit and penetration testing requirements

Open Problems

Needs of Users

- Specifications are nowhere near finished
- The needs of consumers are at odds with those of enterprise users
- CISOs are largely not present at ETSI, 3GPP and ITU

Security of Consumer IoT Products

- Current security methods (ETSI 103 645) don't scale well and are often too slow
- Processors for IoT devices have low power, but also low battery drain – may not have enough processing power for future security requirements, e.g. quantum-safe security
- Roots of trust have to be anchored in a secure boot for devices with integrated UICC, SIMs, eSIMs, etc. (ETSI 103 465) – eSIMs may offer more opportunities for man-in-the-middle attacks

Trusted Environments

- Many new services and user-owned devices on internal networks
- More opportunities for attackers
- Network operators need control over the 5G services for both consumers and enterprise users

Summary

Primary technological forces

- **Radio spectrum** – finite, expensive, scarce in densely populated areas
- **Battery life** – more features consume more power
- **User mobility** – uncontrolled users increase uncertainty in the management of wireless systems

Look for technologies that ease industry constraints…

- Research focus on ubiquitous wireless access and routing
- Information theoretic advances – push more data over the same spectrum
- Advanced antenna techniques – cover more spectrum with less physical space consumption, smart antennas combine signal processing and electromagnetics – smaller mobile devices
- More intelligent radio systems – better cope with user mobility and the increasing number of wireless products and users – add more users
- Cross-layer design – optimize certain applications when used in wireless environment – better, faster data performance

It’s not just about technology…

- Excellent technical solutions are routinely discarded by the industry and consumers because they ignore or aggravate the non-technological forces that constrain the industry
- Standards are a double-edged sword > fuel adoption while limiting innovation
- Tomorrow’s wireless technologies must consider all relevant forces

Dialogue

If you were a network operator, what would be your primary concerns over the next 10 years?

- How would you address revenue erosion?
- How would you charge for high-speed data?

If you were a wireless manufacturer, what would be your primary concerns over the next 10 years?

- Innovation space?
- Areas of investment?

Thank you

Mark Pecen

- **MARK PECEN serves as Advisor to Quantum Valley Ideas Lab, a specialized advanced technology research centre with focus on commercialization of quantum technologies.**
- **He recently served as chairman and founding member of the European Telecommunication Standards Institute (ETSI) Working Group for Quantum Safe Cryptography (Cyber QSC) in Sophia Antipolis, FRANCE since 2015.**
- **Pecen is a retired senior executive of BlackBerry, Ltd. where he founded the Advanced Technology Research Centre and helped to develop a significant portion of BlackBerry's wireless and networking patent portfolio.**

- Pecen has served on over 20 governance and advisory boards for both public and private companies in Canada, Europe and the U.S. and is currently serving on two Canadian university governance boards. He also serves as an advisor to the Canadian government and European Commission on ICT R&D and technology standardization.
- He is a named inventor on more than 100 fundamental patents in wireless communication, networking and computing, and is a graduate of the University of Pennsylvania, Wharton School of Business and the School of Engineering and Applied Sciences.