Evolution of Wireless Communications

Javan Erfanian
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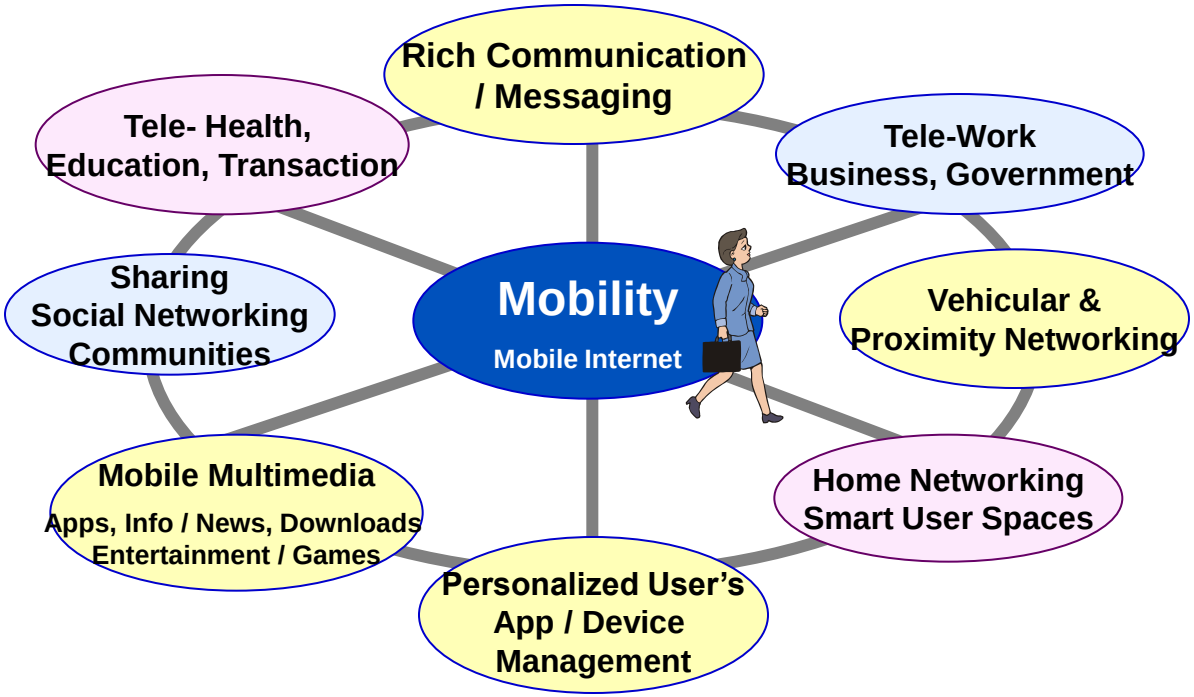
The Picture



What fields are involved in enabling this?!

Telecommunication, Radio, Optics, Computing, software / hardware, electronics, power, multimedia, & many more …

Future?!

Evolution? Innovations? Challenges? Future?

Intention – Context – User Space - Experience

Quality Of Experience

Service Architecture

Networks

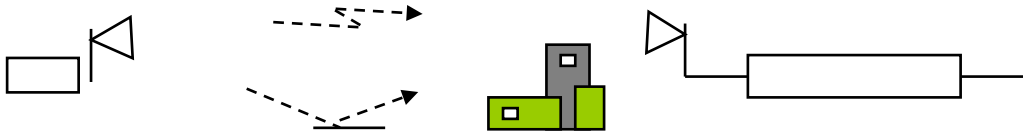
Packet Core Evolution

Coding / Modulation

Spectral Efficiency

Receivers

Antennas



Spectrum

Processing – OS – SW/ HW – Memory – Microelectronics

Power Management

Wireless Technology Evolution

1985

Today

Future?

2010 → NEXT?!

- **Speed, response time, openness, experience, efficiency, …**

Future Internet – Mobility, simplicity, trust, information & content-centric

User device reconfigurability

Heterogeneous & Multi-modal

Sensors & Machine-to-Machine

Operational Efficiency – Self X

Cooperative & Cognitive – Understand, decide, adapt / train

Spectrum Flexibility

Technology Elements To Meet Design Goals - Example

Design Goals	Access Technology Elements
Rich experience & high performance	**Multiple Access mechanism**
Application (personal, local, wide-area mobility; enterprise / campus, home)	**Coding & Modulation**
Connectivity, coverage, roaming	**Radio channel bandwidth**
Universality & ecosystem richness	**Dynamic resource allocation / adaptation**
Efficiency & cost-effectiveness	**Low latency** for real-time IP (e.g. **VoIP**)
	Spectrum band
	Advanced antenna technologies (e.g. **MIMO**)
	Others

Wireless Access Technology Advancement

Design Goals
Rich experience & high performance
Application (personal, local, wide-area mobility; enterprise / campus, home)
Connectivity, coverage, roaming
Universality & ecosystem richness
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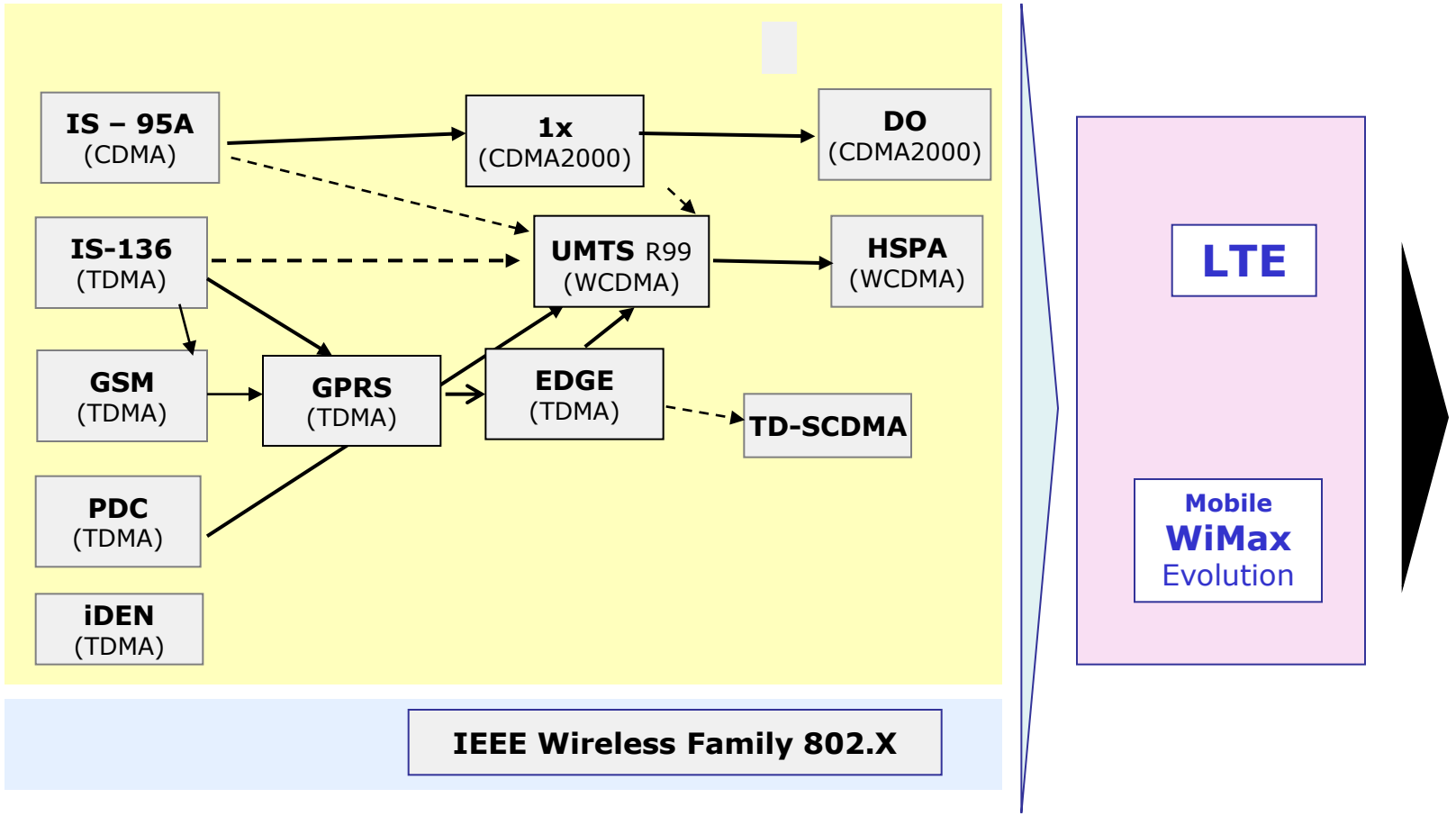
Access Technology Elements
Multiple Access mechanism
Coding & Modulation
Radio channel bandwidth
Dynamic resource allocation
Low latency for real-time IP (e.g. **VoIP**)
Spectrum
Advanced antenna technologies
Others

LTE

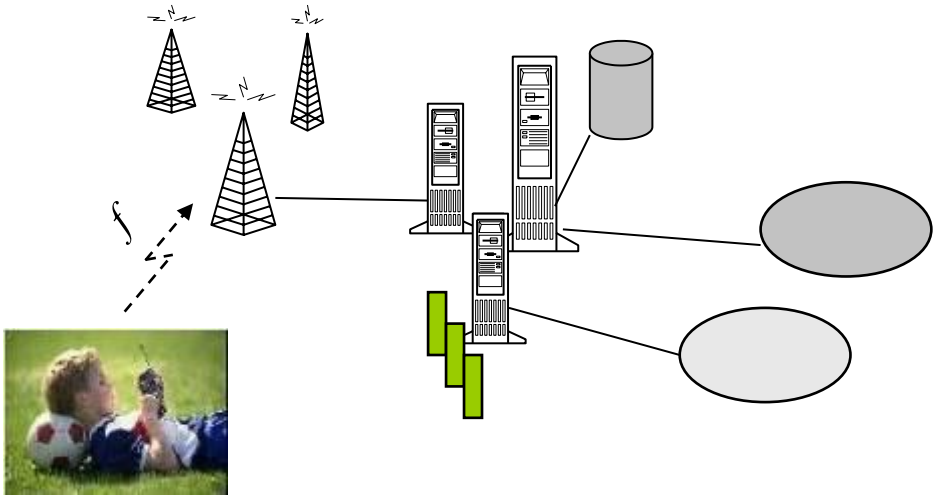
OFDMA
/ SC-FDMA
Higher-Order
Flexible
1.4 to 20 MHz
Link Adaptation
Several milliseconds
in user-plane
Flexible,
FDD/TDD
MIMO
HARQ
FFR
Antenna Systems
eMBMS, etc.

Mobile Technologies - 2G to Beyond 3G



*** Not all technologies or transitions are shown**

How is this architecture & experience evolving?



Dynamic Adaptive Re-configurable Virtual

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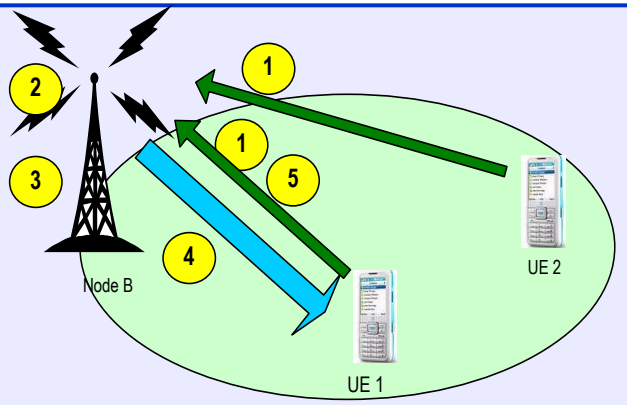
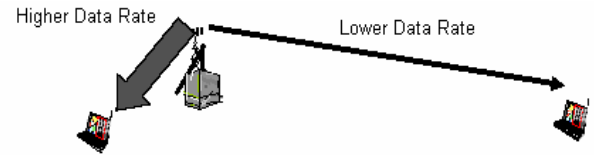
3G Examples & Evolving

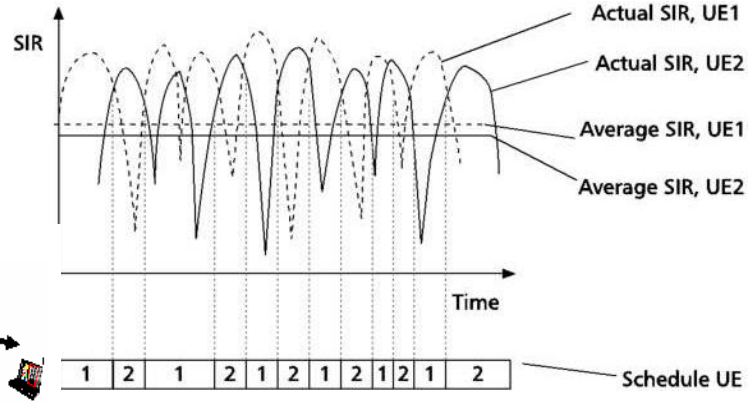
HSPA & DO dynamically respond to link conditions to send more data at shorter time. The idea is simple:



- Channel Quality
- Scheduling
- Adaptive coding / modulation

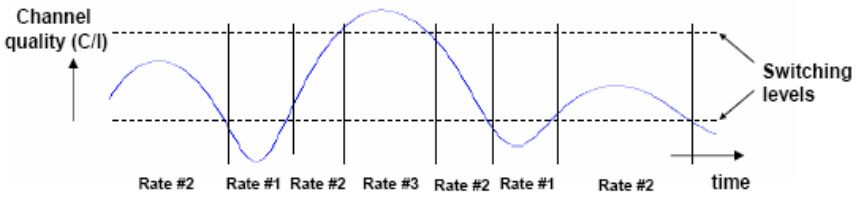
Link Adaptation





Fast Link adaptation:

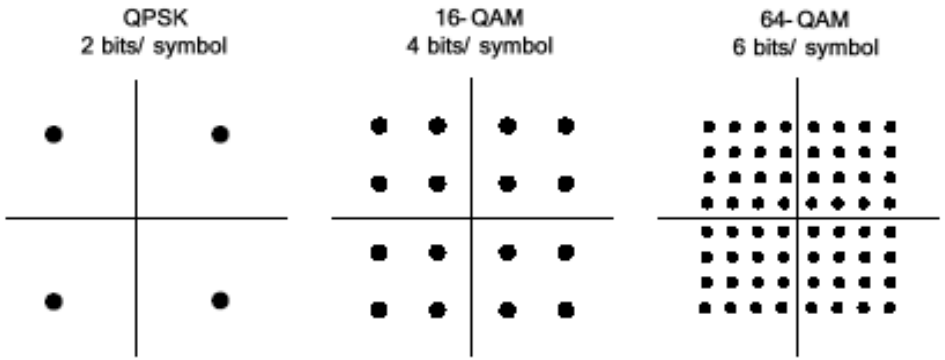
Rate #3: e.g. 16-QAM, R=3/4
Rate #2: e.g. QPSK, R=3/4
Rate #1: e.g. QPSK, R=1/2

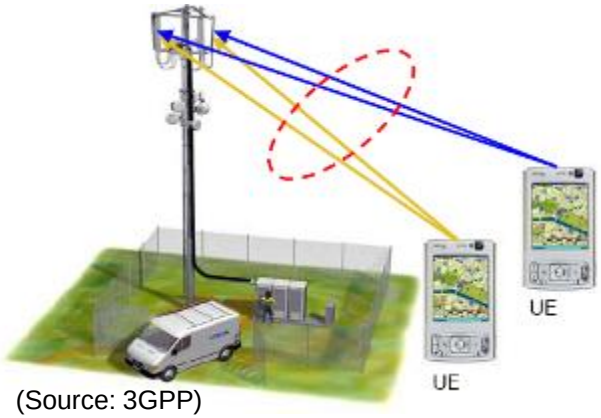


Scheduling

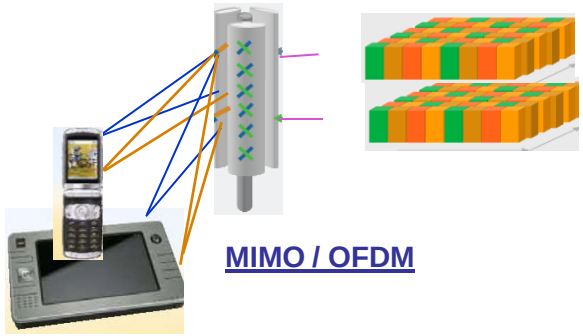
Rate selection based on radio link conditions

QAM, MIMO, OFDM, …



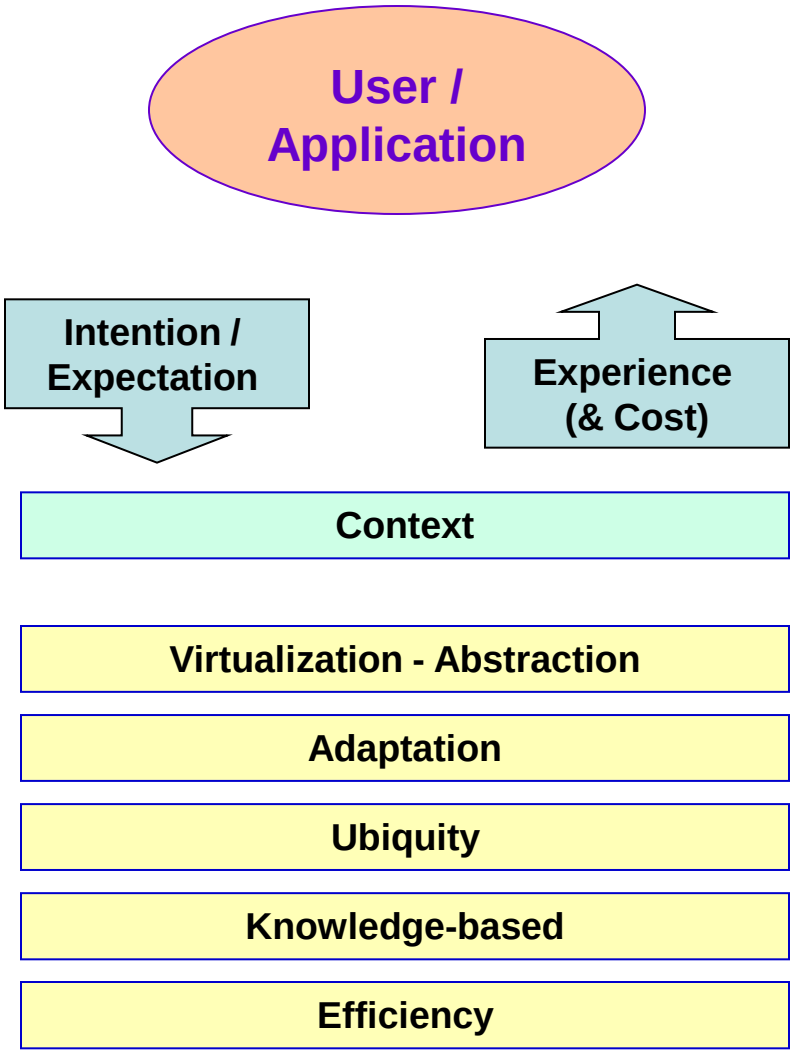


(Source: 3GPP)



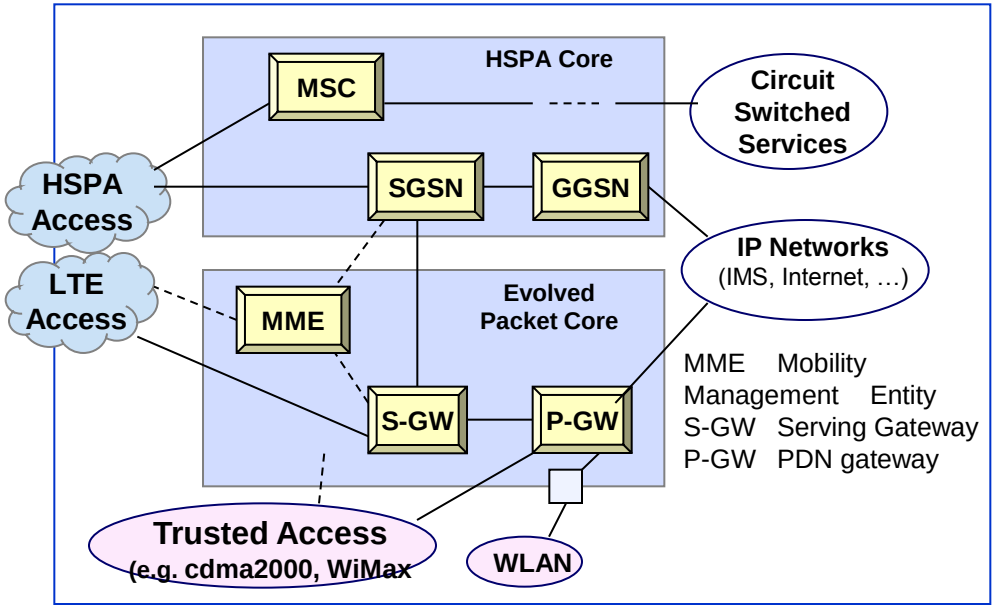
MIMO / OFDM

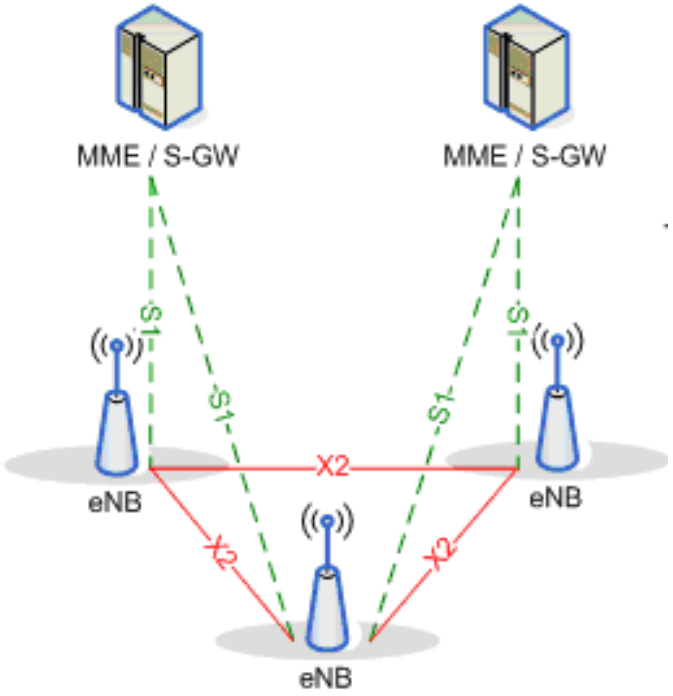
Research, Innovations, & Technology Evolution Paradigms



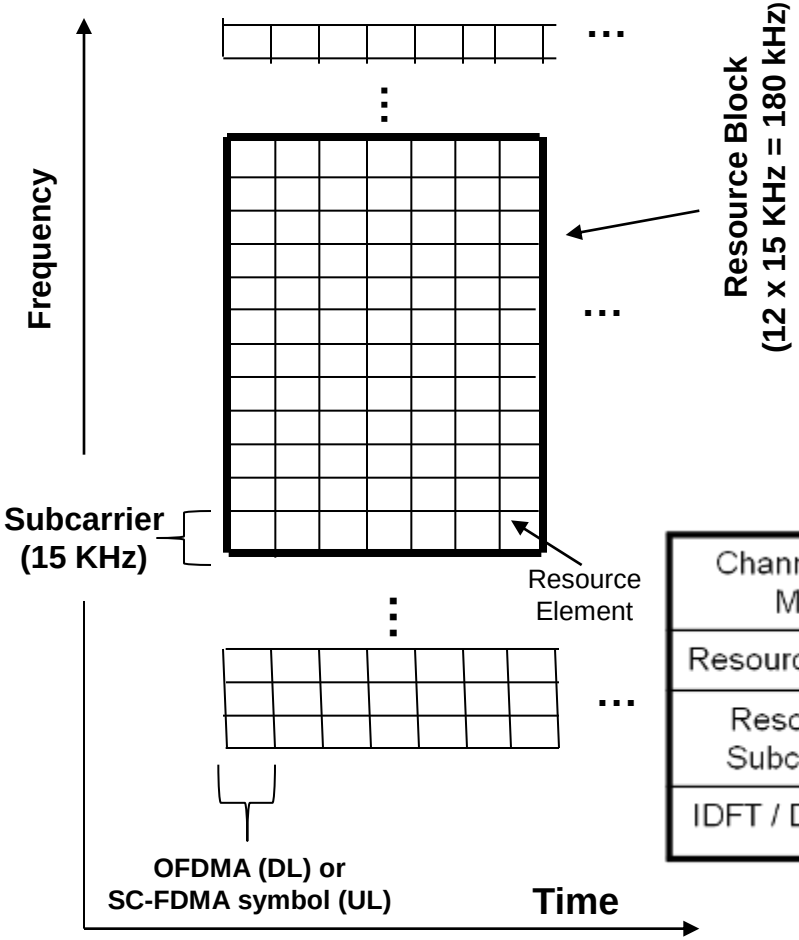
LTE / EPC Architecture

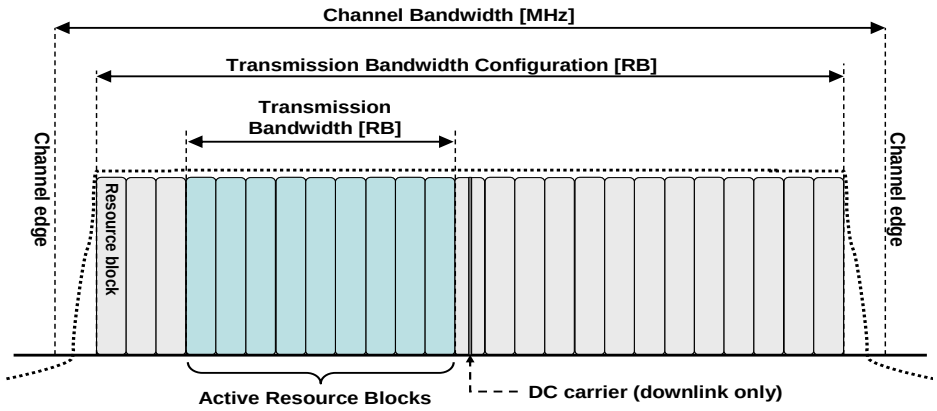
- **Simplified to a flatter architecture with an Evolved Packet Core and Evolved- UTRAN (e-NodeB)**





LTE Physical Layer Transmission

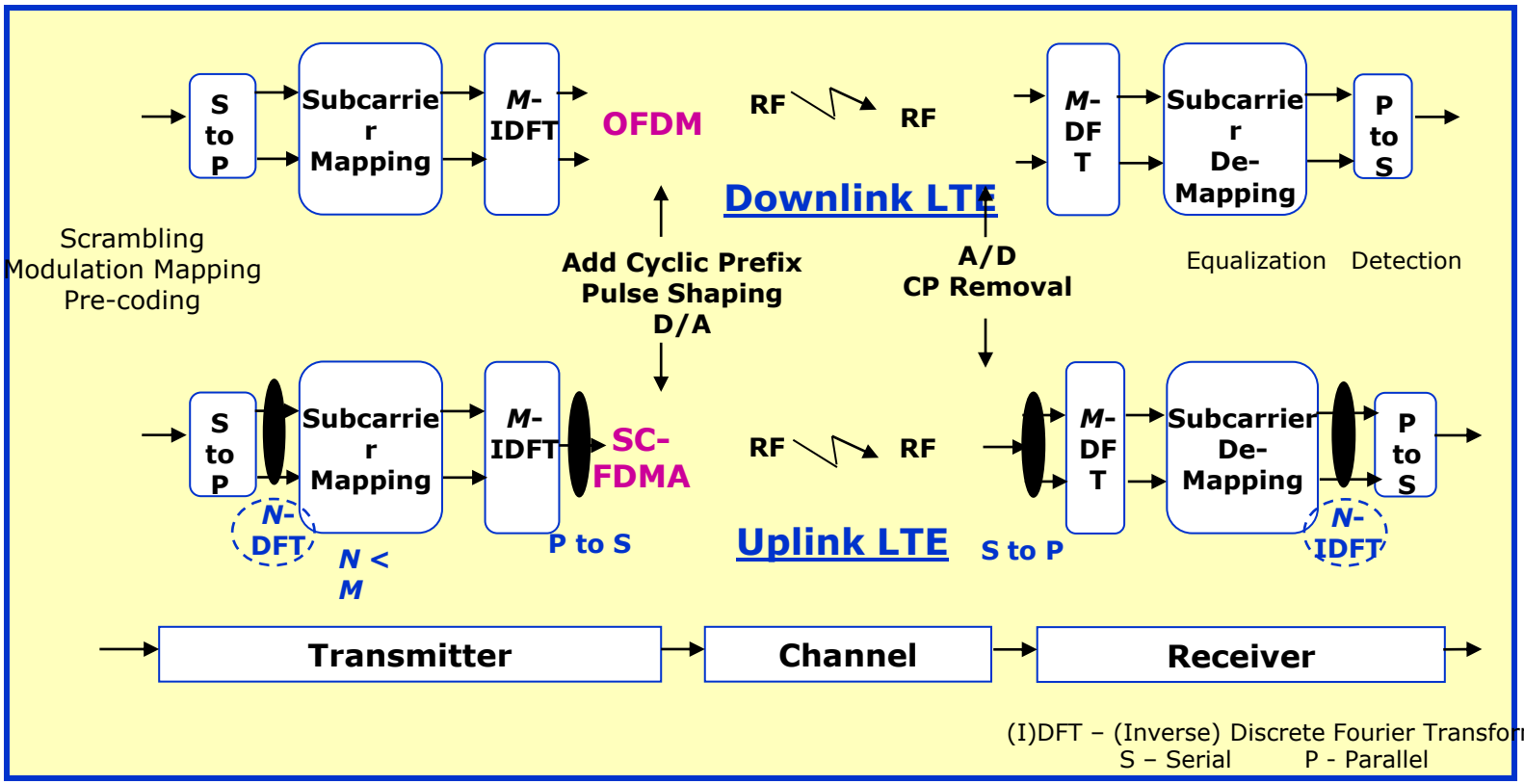




Channel BW, MHz	1.4	3	5	10	15	20
Resource Blocks	6	15	25	50	75	100
Resourced Subcarriers	72	180	300	600	900	1200
IDFT / DFT Size	128	256	512	1024	1536	2048

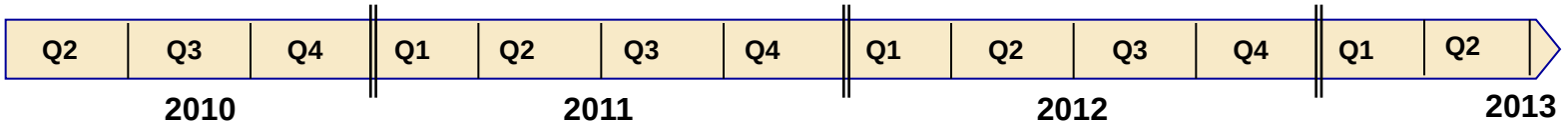
(I)DFT – (Inverse) Discrete Fourier Transform

LTE Transmission, *Cont'd*



- **Frequency domain equalization (using DFT) with lower complexity for broadband channels**
- **SC-FDMA used for uplink**

LTE Ecosystem Evolution At A Glance



LTE Global Introduction

LTE Rollout **Full LTE / HSPA Ecosystem**

Continued Global LTE Trials

LTE data only
Generally multimode multiband

LTE Handsets

LTE Voice & Data

LTE bands

Operational Efficiency

Self-Organizing Networks (SON)

Spectrum Auctions

Data Traffic Growth

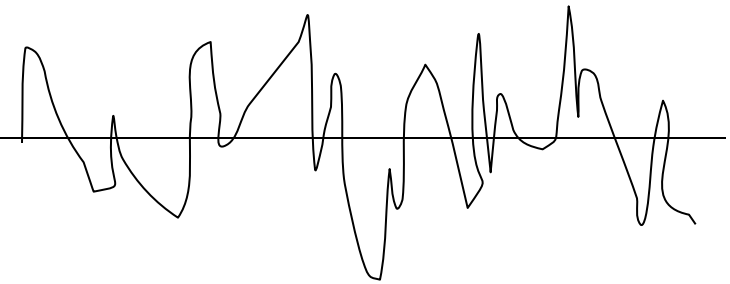
Capacity **Modeling Irregular Behaviour** **Cost**

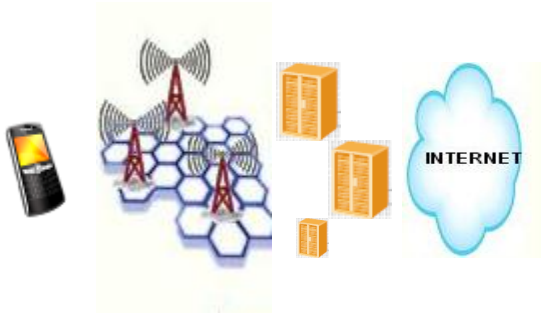
Capacity Enhancements

- **Network-Level**
- **Application Optimization**
- **Operational Efficiency**

Enable

Save Energy





Operational Excellence

- Spectral Efficiency
- Adaptive Technologies – Adaptive Resource Partitioning
- Dynamic Resource Allocation
- Flat & Simplified Architecture
- Granular Traffic Management - Knowledge-Based & Policy-Based
- Automation & Self-Organizing

Operational Efficiency - Motivation

- Configure A New Network Element Without major Impact
- Automatic Neighbour Cell Relations

- Balance Load Between Cells
- Dynamically Optimize Capacity & Coverage --- & Performance
- Remove Coverage Holes & Reduce Interference Dynamically

- Save Energy When Unloaded / Under-loaded In Real Time

- Diagnostics & Healing Only Where & When Needed – Self Organizing

Mobile Device – A Platform

Look & Feel

Interaction & Usability

Personalization & Adaptability

Mobile Internet
(App / Software)

Platform!

Communication

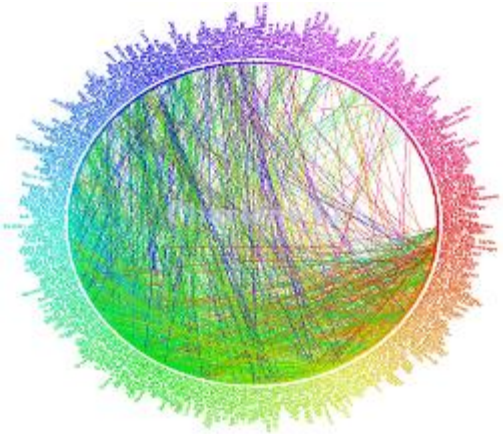
Computing & OS

power

Presentation

CE

Sensing



Long Term View

1985

Today

Future?

Nanotechnology

- Electronics & Processing
- Power / Energy, Memory, …
- Display, Sensing & Interaction, …

- Peripheral Structures – Surface Properties & Significance of Mechanical properties

- MATERIAL
  - Light, Rigid / Stiff & yet Tough, Flexible
  - Self-Cleaning / Healing & Assembly Properties – Adhesive Properties

- Optimize – e.g. Strength, stiffness and elasticity
- High Power Reconfigurable Surface Grid Communication

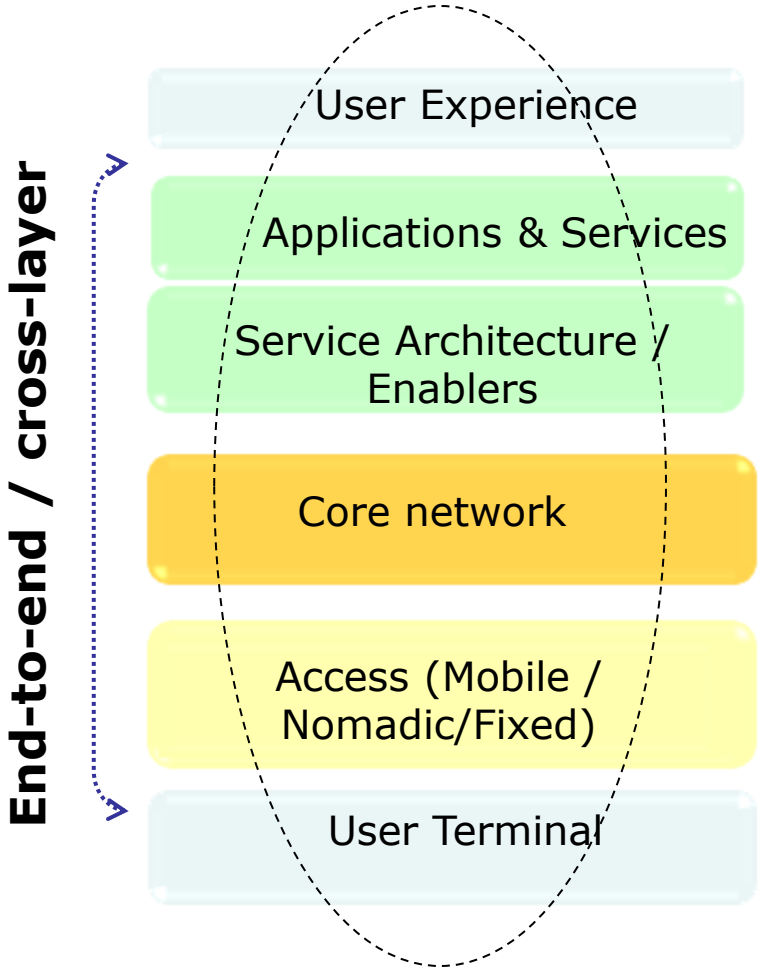
Nanomaterial

- Nanocomposites have these prospects
  - Strength & Toughness
  - Light Structures
  - Easier Processing
  - Improved thermal, electrical, and mechanical properties
  - Surface qualities
  - Energy harvesting
  - In addition to enabling new possibilities …
  - Example
    - CNT
      - High aspect ratio, low density & lightweight, high tensile strength, multifunctional, flexible, lateral size, others …

Range of Applications!

Challenges!

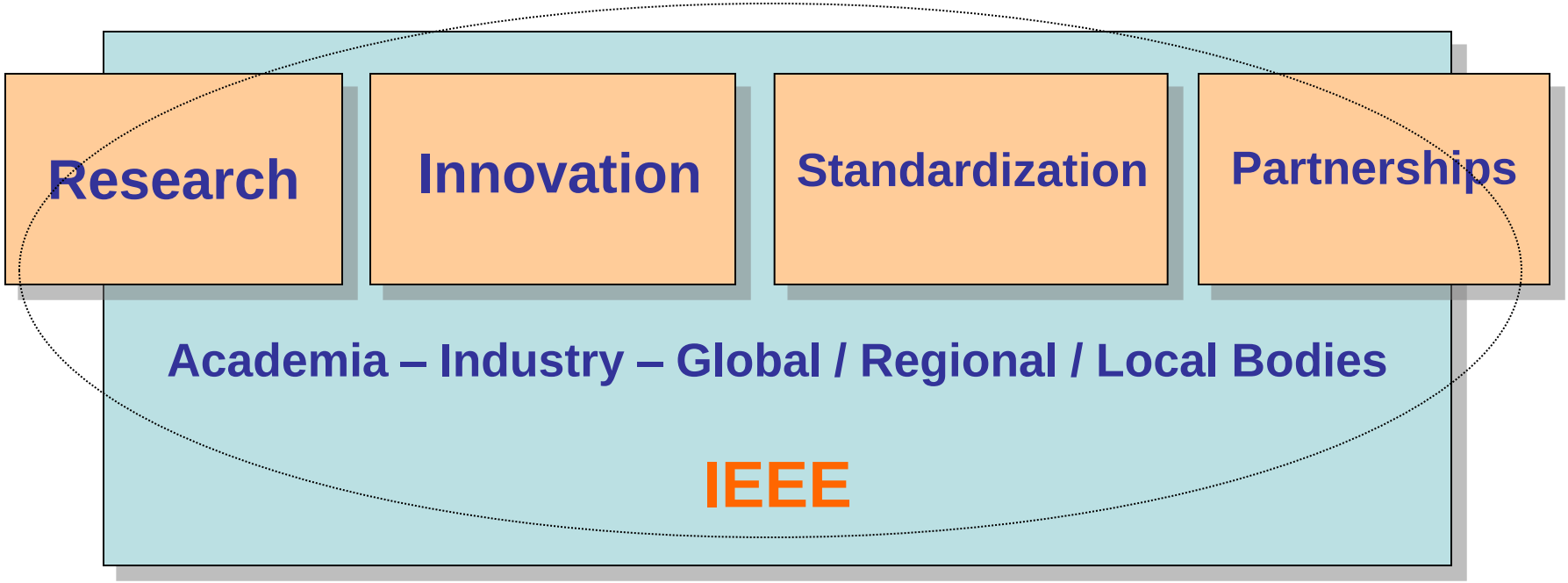
Research



- **Future of User Interaction**
- **Definition of "Value"**
- **Concept of "Service" in Future**
- **Identity, security, charging**
- **Service Framework – Abstraction**
  - Creation, Access, Delivery
- **IP Networking**
- **Ad-hoc Networks**
- **Heterogeneous Networks**
- **Sensing**
- **Broadband Wireless**
- **Spectrum Management, Cognitive**
- **Seamless Access**
- **Intelligent Radio**
- **Processing, power, memory, display, OS, nano-engineering, robotics, neural, bio-engineering**
- **……..**

Building The Future

Together!



Thank You!