Broadband Wireless Landscape

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Outline

- **Motivation for 4G**
- Overview and status of 4G
- Advances in 4G Technologies
- Future Research Directions

Explosive Growth in Mobile Internet Devices, Applications, and Traffic

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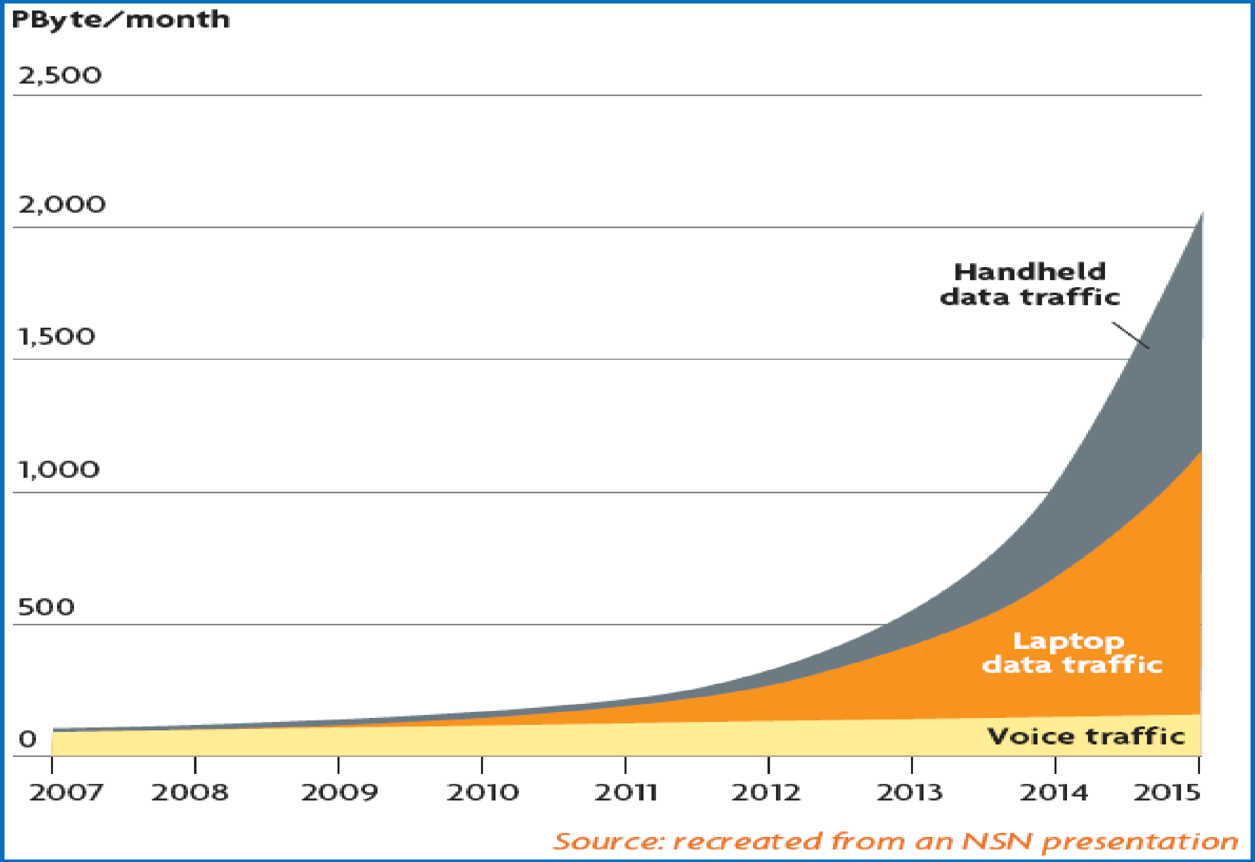
++ These are examples of applications & services

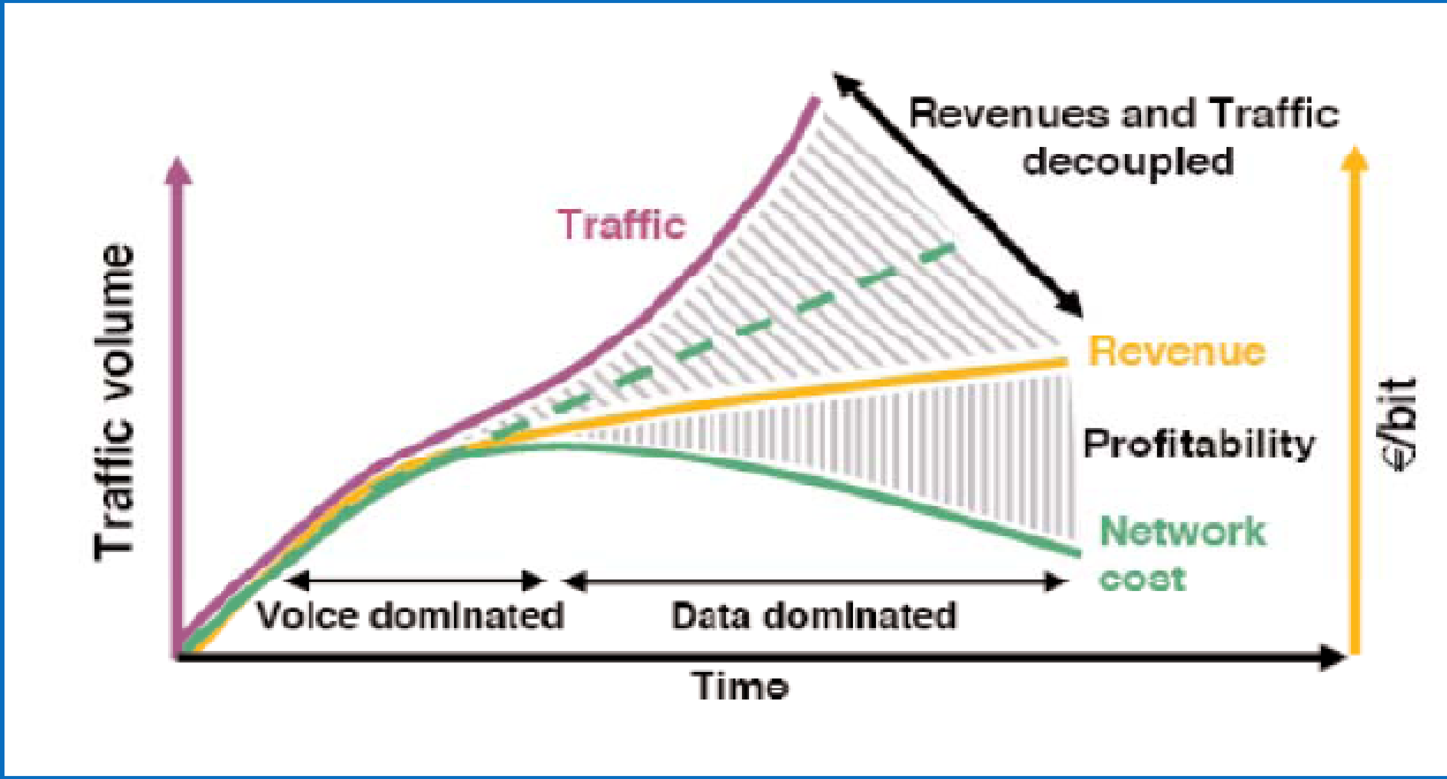
What Is Happening in the Marketplace?



- Broadband traffic is growing exponentially with introduction of:
  - new devices
  - Larger screen devices

Challenge – Lower Revenue Per Bit

- Cost of Network deployments to meet demand is increasing faster than revenue

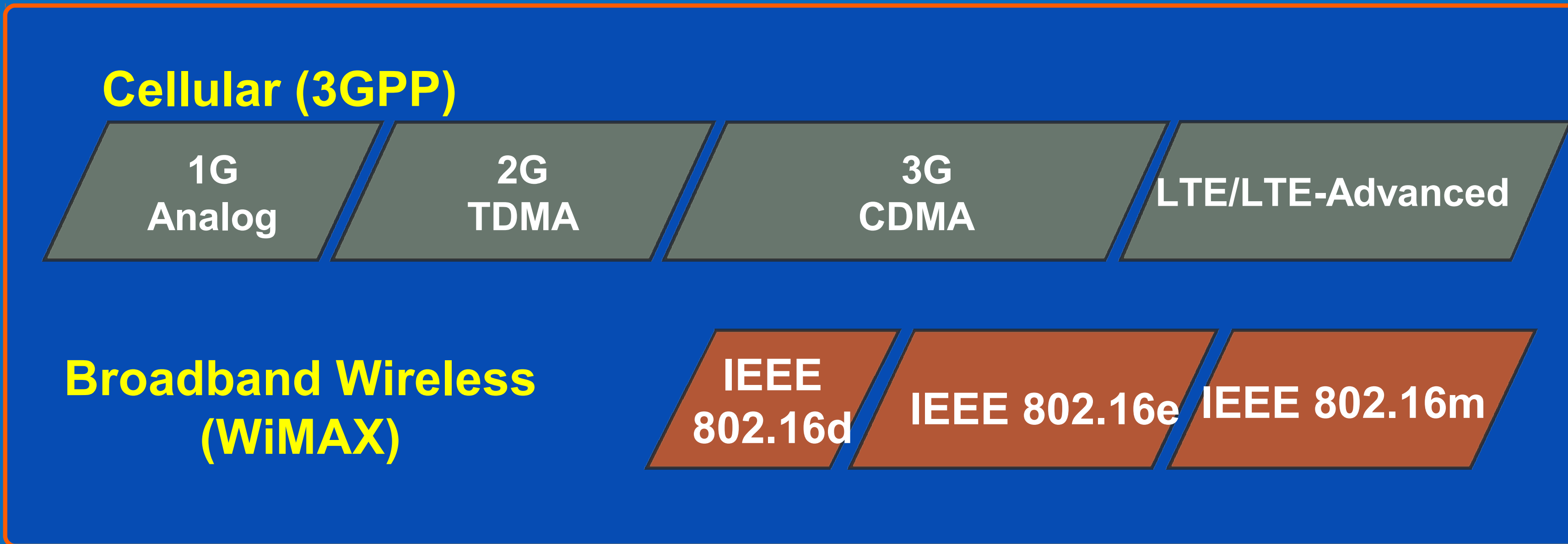


4G networks needed to lower Cost per Bit, and enable new Services

Outline

- Motivation for 4G
- **Overview and status of 4G**
  - **3GPP LTE**
  - IEEE 802.16/WiMAX
- Advances in 4G Technologies
- Future Research Directions

Evolution of 4G



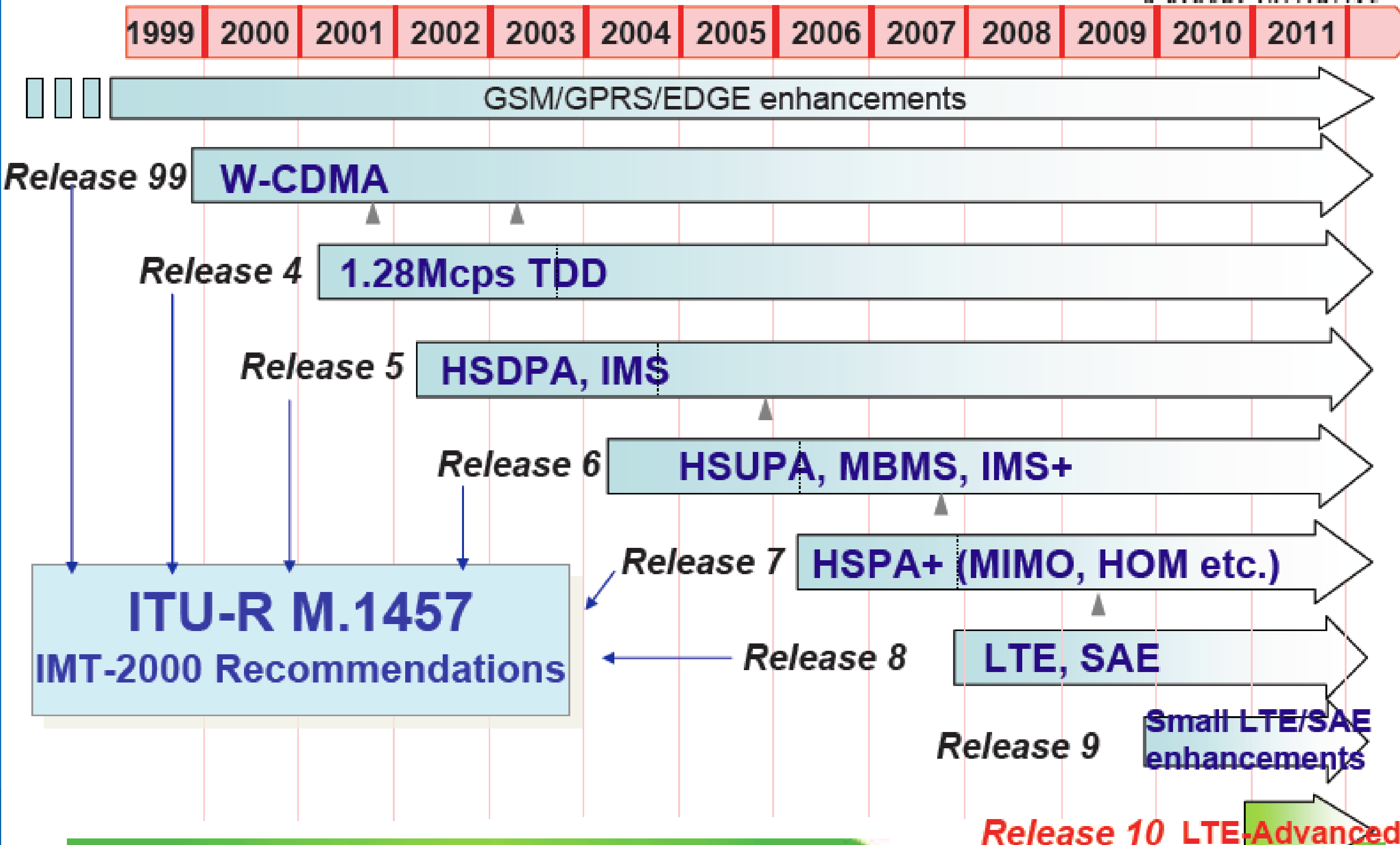
Current 4G standards: Part of IMT-2000

- WiMAX (based on IEEE 802.16e)
- LTE (Rel. 8)

4G+ candidates: Part of IMT-Advanced

- WiMAX2 (based on IEEE 802.16m)
- LTE-A (Rel. 10)

Release of 3GPP specifications



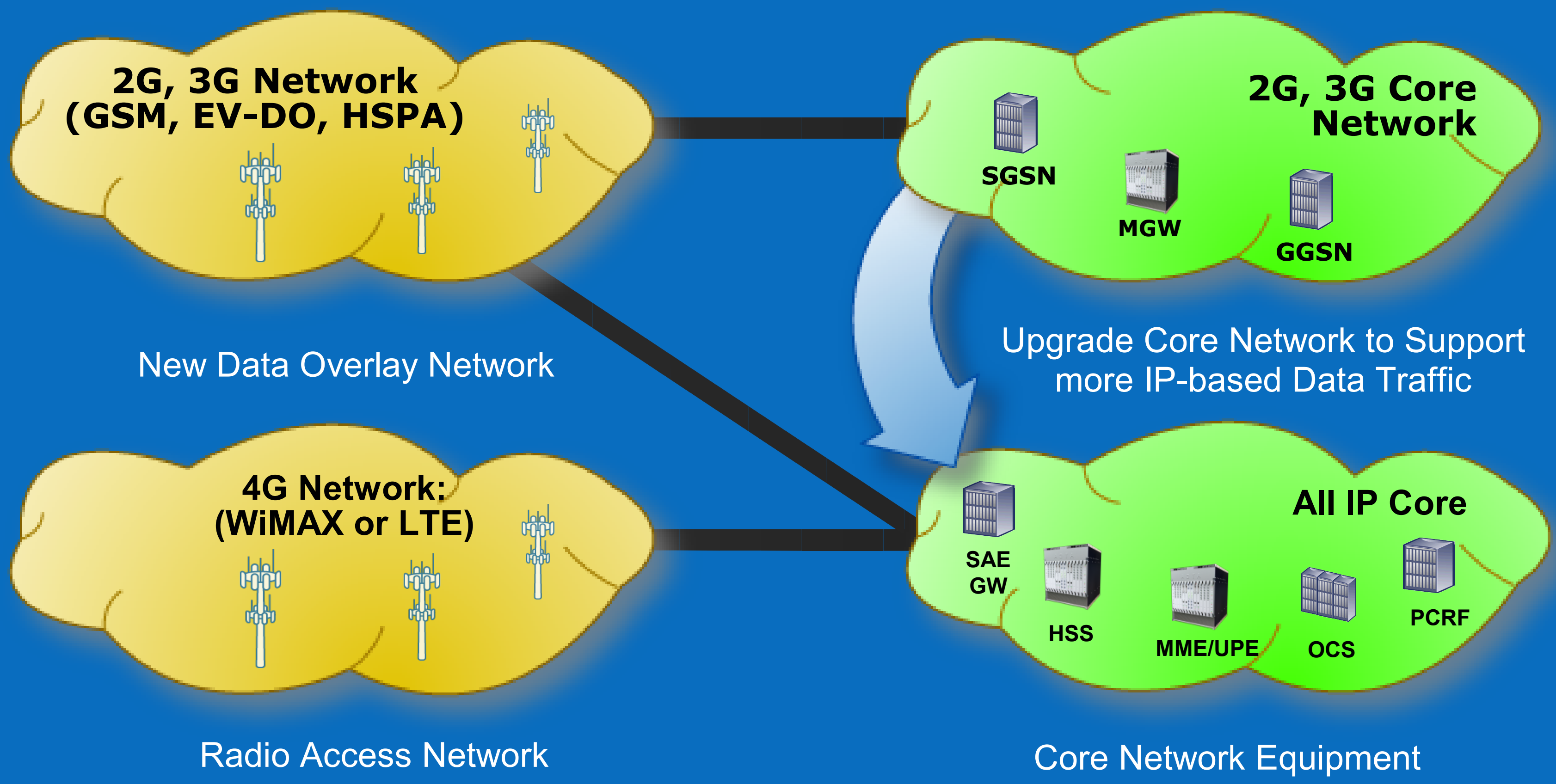
Requirements of 3GPP LTE-Advanced/IEEE 802.16m

Requirements	IMT-Advanced	IEEE 802.16m	3GPP LTE-Advanced
Peak spectrum efficiency (bit/sec/Hz) (system-level)	DL: 15 (4x4) UL: 6.75 (2x4)	DL: 8.0/15.0 (2x2/4x4) UL: 2.8/6.75 (1x2/2x4)	DL: 30 (8x8) UL: 15 (4x4)
Cell spectral efficiency (bit/sec/Hz/sector) (system-level)	DL: (4x2) = 2.2 UL: (2x4) = 1.4 (Base coverage urban)	DL: (2x2) = 2.6 UL: (1x2) = 1.3 (Mixed Mobility)	DL: (4x2) = 2.6 UL: (2x4) = 2.0
Cell-edge user spectral efficiency (bit/sec/Hz) (system-level)	DL: (4x2) = 0.06 UL: (2x4) = 0.03 (Base coverage urban)	DL: (2x2) = 0.09 UL: (1x2) = 0.05 (Mixed Mobility)	DL: (4x2) = 0.09 UL: (2x4) = 0.07 (Base coverage urban)
Latency	C-plane: 100 msec (idle to active) U-plane: 10 msec	C-plane: 100 msec (idle to active) U-plane: 10 msec	C-plane: 50 msec (idle/camped state to connected) 10 msec (dormant state to active state) U-plane: 10 msec
Mobility bit/sec/Hz at km/h (link-level)	0.55 at 120 km/h 0.25 at 350 km/h	Optimal performance up to 10 km/h Graceful: degradation up to 120 km/h Connectivity up to 350 km/h Up to 500 km/h depending on operating frequency	Optimal performance up to 10 km/h Up to 500 km/h depending on operating frequency
Handover interruption time (msec)	Intra frequency: 27.5 Inter frequency: 40 (in a band) 60 (between bands)	Intra frequency: 27.5 Inter frequency: 40 (in a band) 60 (between bands)	Not specified

3GPP LTE Key Features

- ✓ **High spectral efficiency**
  - OFDM in Downlink
  - Single-Carrier FDMA in the Uplink
  - Multi-antenna application
- ✓ **Very low latency**
  - Short setup time and Short transfer delay
  - Short HO latency and interruption time
    - Short TTI
    - RRC procedure
    - Simple RRC states
- ✓ **Support of variable bandwidth**
  - 1.4, 3, 5, 10, 15 and 20 MHz
- ✓ **Simple Architecture, protocol architecture**
- ✓ **FDD and TDD within a single radio access technology**

Network Upgrade to Support 4G



Mobile WiMAX and 3GPP LTE require new Radio Access Networks and devices.
Neither is "backward compatible" to 3G unless user has a dual mode device.

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Status of IEEE 802.16m/WiMAX

- Mobile WiMAX: Rel 1.0 (802.16e) → Rel 1.5 → Rel 2.0 (802.16m)
- IEEE 802.16 Task Group m (TGm) is developing an 802.16 amendment (802.16m) which provides performance improvements.
- Meet/Exceed IMT-Advanced requirements for next generation mobile networks.
- The 802.16m spec is currently at sponsor ballot stage and was recently approved to be included in the family of IMT-Advanced.

Mobile WiMAX Roadmap

Rel 1.0
802.16e-2005

Rel 1.5
802.16e Rev 2

Rel 2.0
802.16m

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Advanced MAC Features in 3GPP LTE-A

- **Relay**
  - support multi-hop relay mechanisms
- **Carrier Aggregation (CA)**
  - enables a common MAC entity to control a PHY spanning over multiple frequency channels with different bandwidths
- **Multi-Radio Coexistence**
  - supports concurrent operations of LTE-A and other collocated radios
- **Fast Dormancy - Power Saving Mechanisms**
  - Quick switch to low power state
- **Self Organization**
  - supports self configuration and self optimization mechanisms
- **Improved QoS Mechanisms**
  - To support variable rate coders over best effort when bandwidth available
- **Machine Type Communication**
  - Basic features
- **GPS assisted Location Based Services**

Advanced MAC Features in IEEE 802.16m

- **Relay**
  - support multi-hop relay mechanisms.
- **Multi-carrier (MC)**
  - enables a common MAC entity to control a PHY spanning over multiple frequency channels with different bandwidths
- **Multi-Radio Coexistence**
  - supports concurrent operations of IEEE 802.16m and other collocated radios
- **Interference Management**
  - manage the inter-cell/sector interference.
- **Group Resource Allocation**
  - Decrease overhead, and increase capacity for VoIP
- **Self Organization**
  - supports self configuration and self optimization mechanisms
- **Improved Power Saving Mechanisms**
  - Idle and Sleep modes
- **Improved QoS Mechanisms**
  - Adaptive polling and granting mechanism
- **GPS assisted Location Based Service**

Deep Dive on one Feature:
-Group Resource Allocation in 16m

Why VoIP over 4G/WiMAX?

- Real-time services will be an essential component of 4G/WiMAX networks.
  - Voice is still a major revenue source for operators.
- WiMAX networks are well-known for high packet-data efficiency, but not for voice efficiency.
  - Hence, efficient support of voice over WiMAX is needed.

VoIP is an Essential Component of 4G/WiMAX

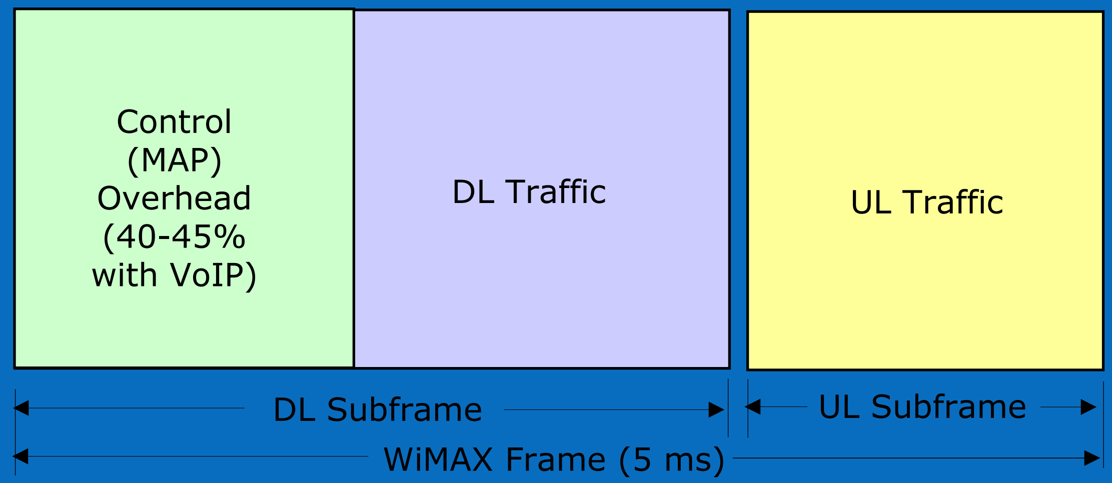
Challenge: Large Control Overhead

WiMAX Control (MAP) overhead → Proportional to number of users scheduled

VoIP traffic → Small packets → More users in frame as compared to data traffic

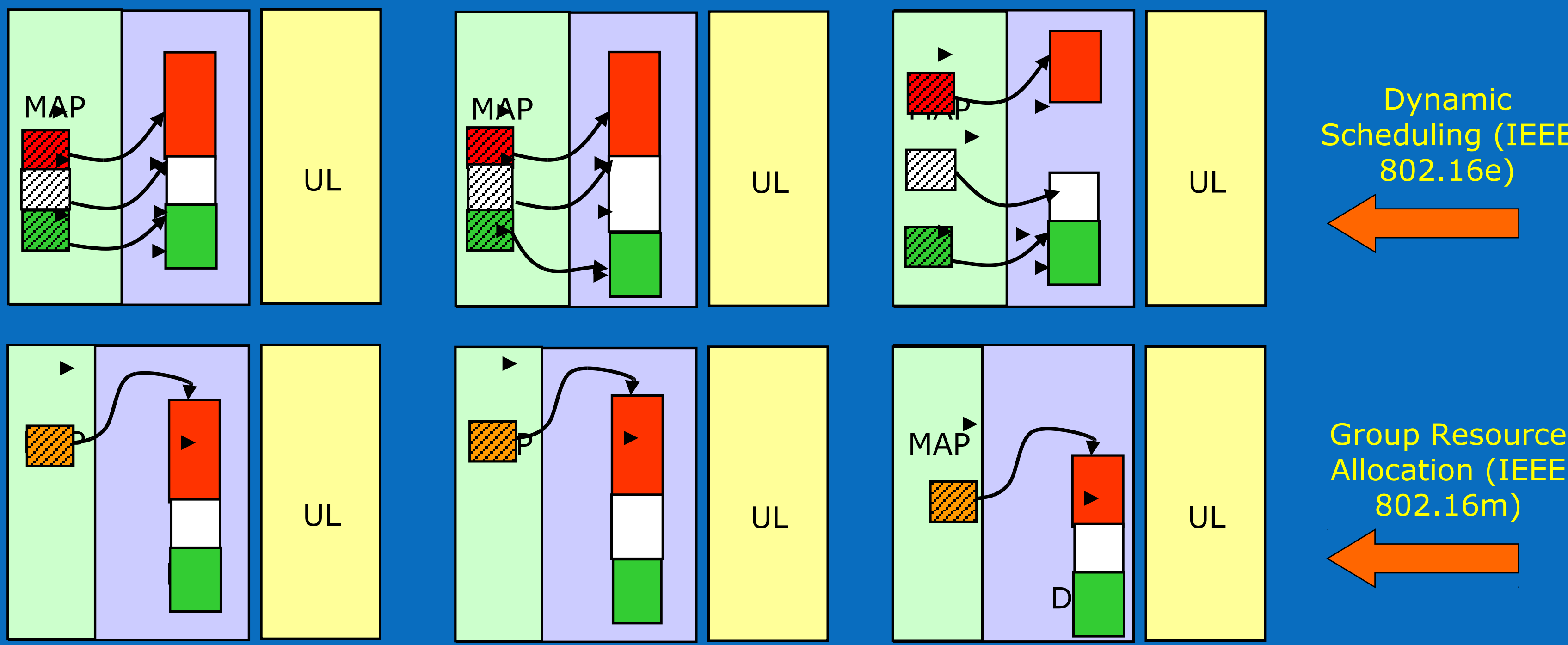
Thus, large control overhead with VoIP traffic

- Up to 40 – 45% of DL subframe



High Control Overhead Results in Low User Capacity

Group Resource Allocation



Users are provided allocations together as a group

Allocation parameters are signaled as small bitmaps saving overhead

Group Resource Allocation Increases WiMAX VoIP Capacity by 40%

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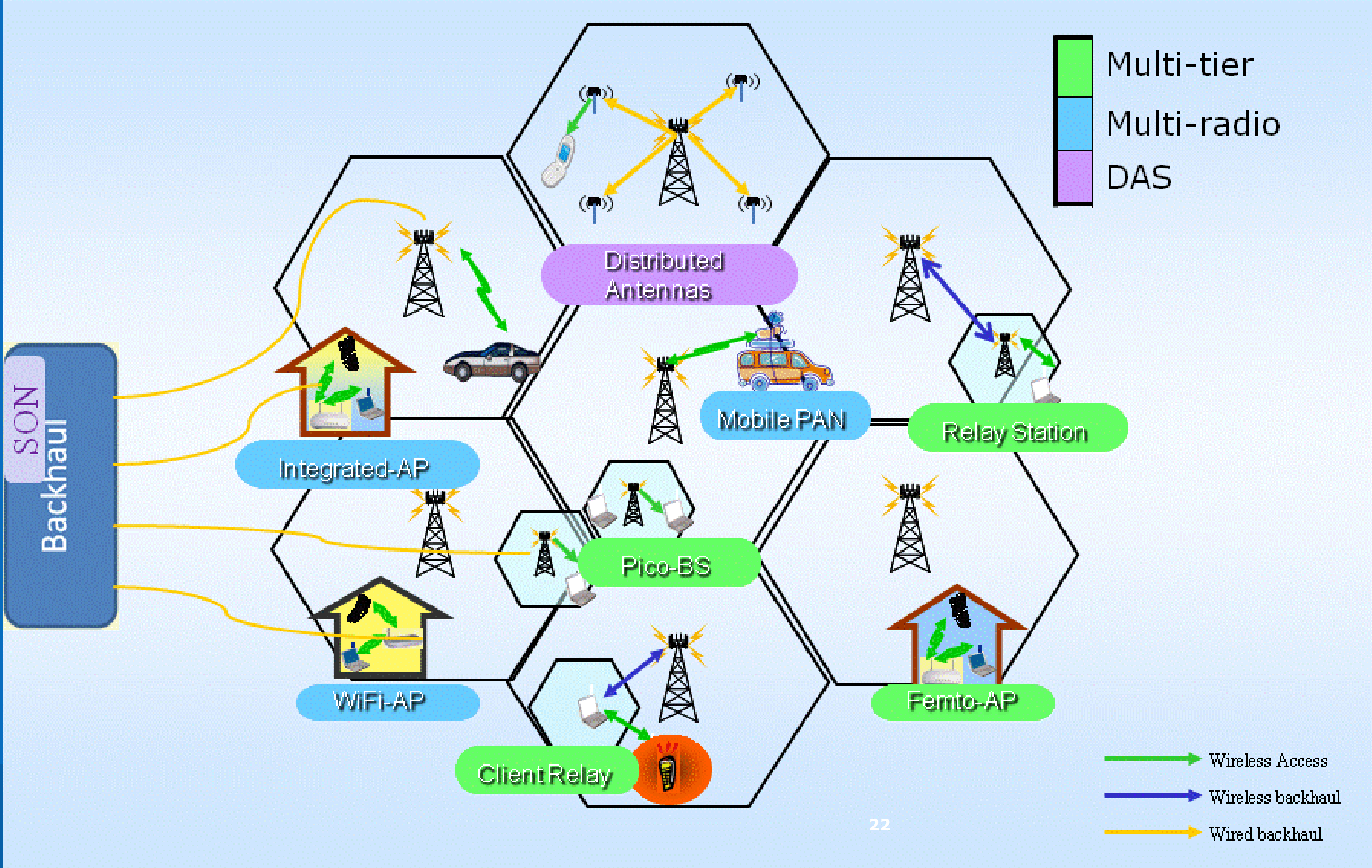
Few Research Directions

- Future Access Networks and Challenges
  - Vision of Advanced Access Networks
  - Multi-tier Networks
  - Interference Mitigation/Alignment
  - Multi-Radio Scenarios
  - Mobility and Network Management
- Enhancing Quality of Experience (QoE)
- Machine Type Communications
- Environment-Friendly Green Radios

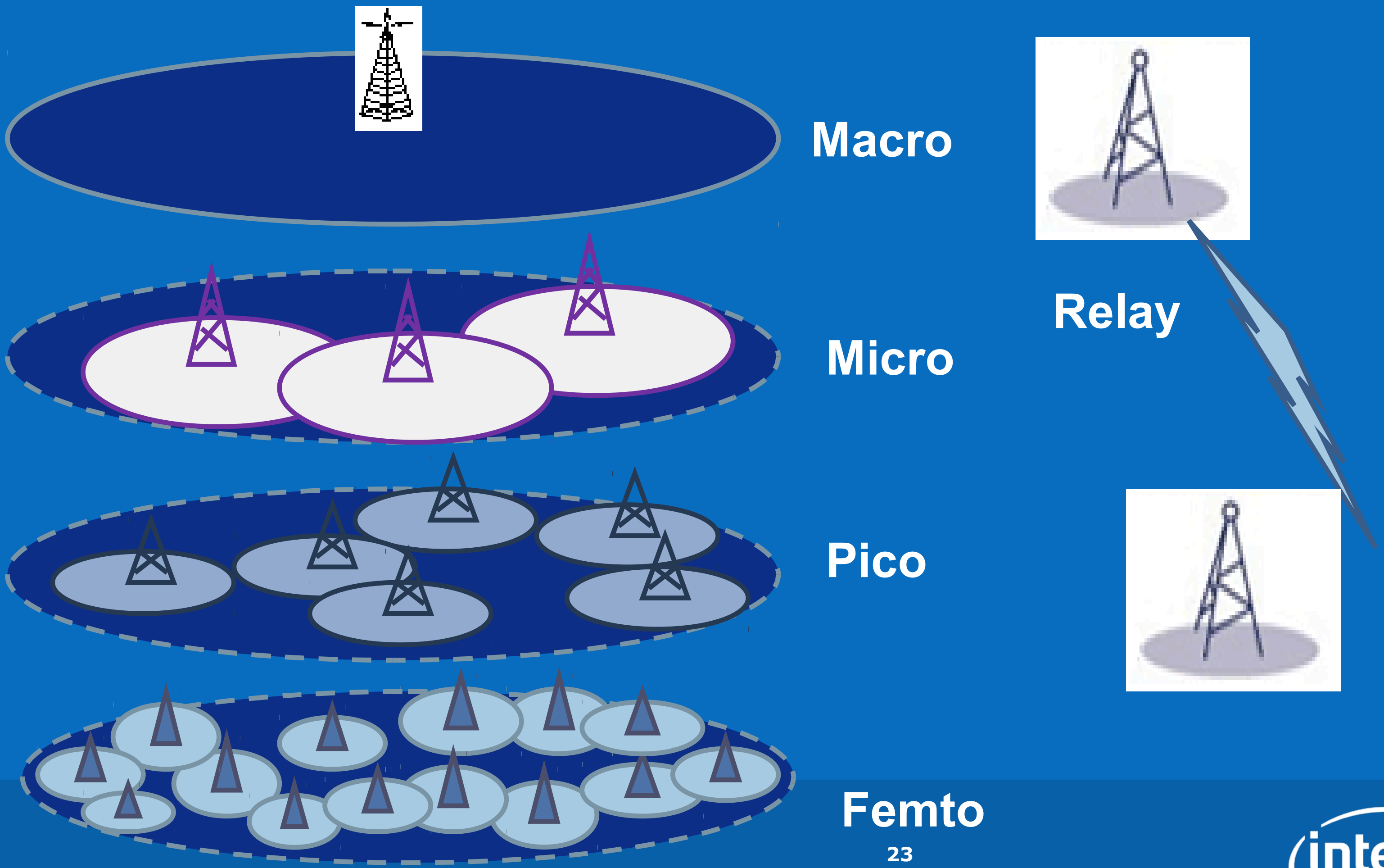
Vision of Advanced Access Network Architecture



Multi-tier Networks

Aggressive Spectrum Utilization

- Overlay multiple tiers of cells, macro/pico/femto, potentially sharing common spectrum



Interference Alignment

Problem

- Inter-Tier Interference is a Challenge. Example: Femto-cells interfere with macro-users and other femto-cells

Idea

- Align transmit directions so that interfering signals all come from the same “direction”. Alignment can be across antennas, frequency, time.

Benefits:

- Improves uplink and downlink transmissions of cell-edge users;

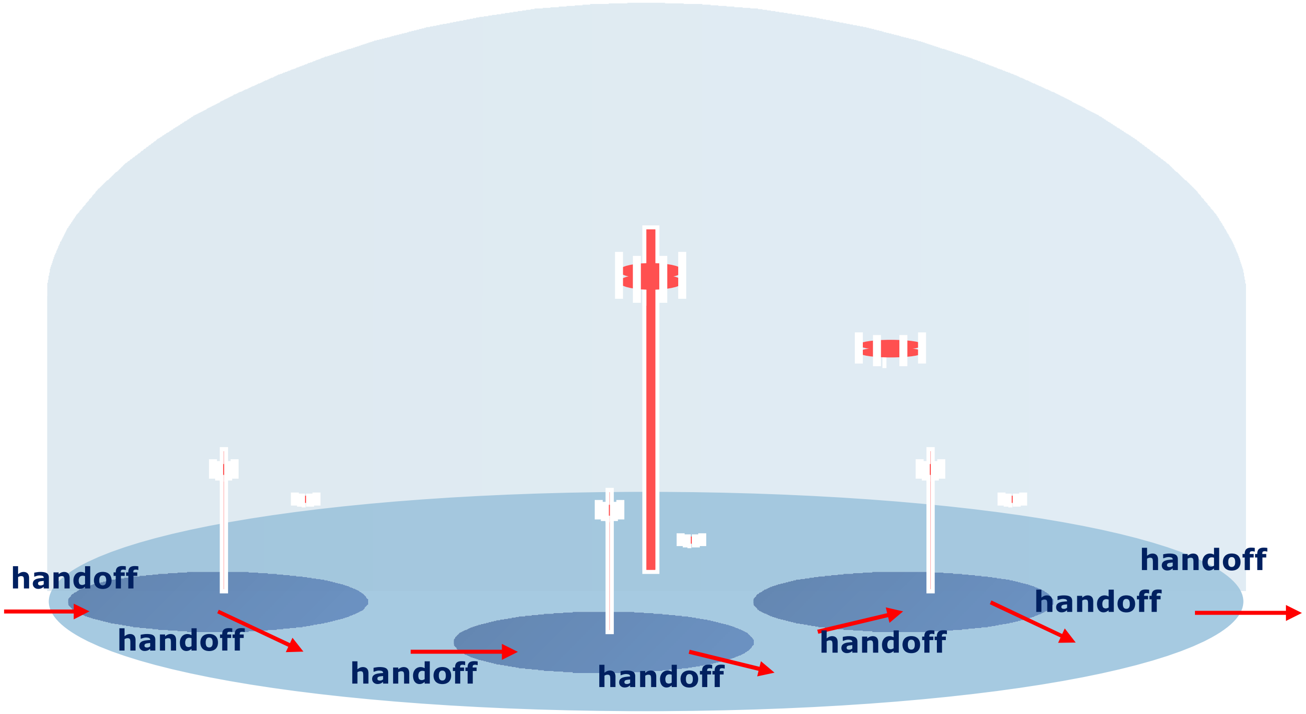
Challenge:

- Practical schemes that can achieve theoretical gain

Mobility & Network Management is a Challenge

Intelligent Handoffs

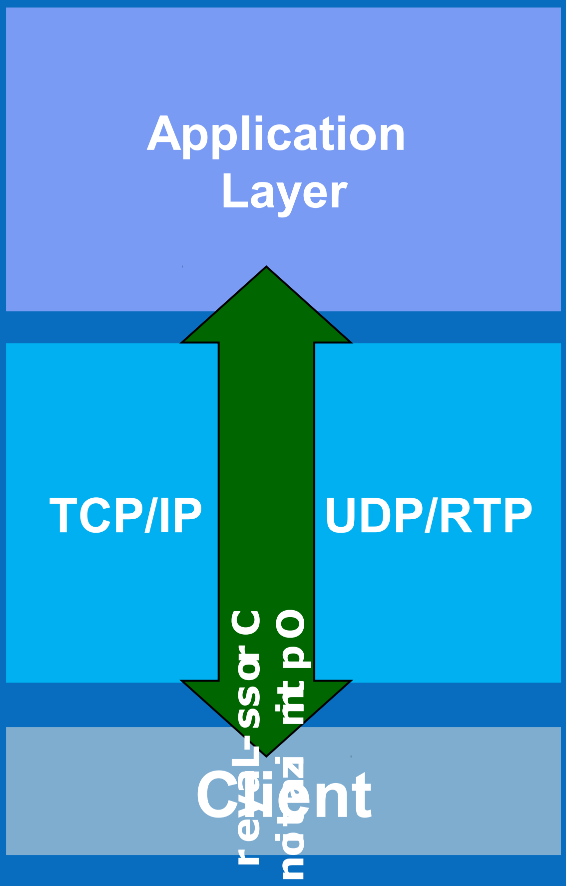
- Efficient handover mechanisms required to avoid frequent handoff between small cells



Multi-Radio Scenarios

Enhancing QoE

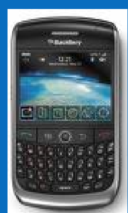
- **Many Devices/Applications Require Enhanced QoE**
  - Expect large number of heterogeneous mobile internet devices with various applications requiring a range of quality of experience (QoE) metrics
- **Limitations of Today's QoS Approach**
  - Not straightforward to map today's QoS parameters to user experience
  - Lack of cost effective solutions for current/future Internet Apps
- **Cross-layer awareness to provide the desired QoE enhancements**
  - QoE-aware link adaptation and resource allocation
  - Intra-flow and inter-flow prioritization at device/network levels
  - Link-aware application adaptation for better QoE and capacity enhancements



Environment-friendly Green Radios

Consumer

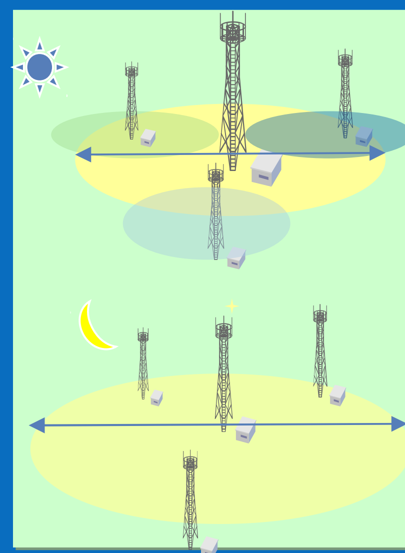
Long Battery Life



Energy Saving Products

Network

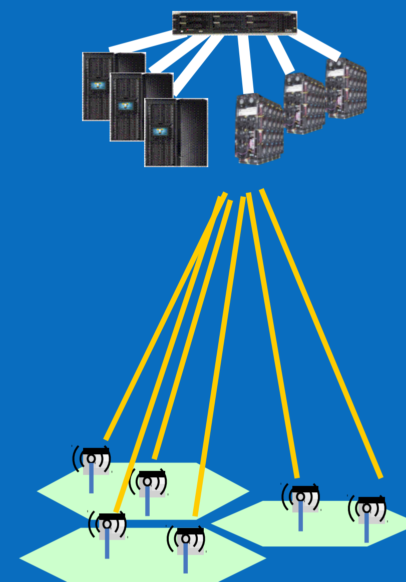
Reduced OPEX, Govt. Regulations



Protocols

Environmental

Low CO2 & Radiation



Architectures

Summary and Final Remarks

- Mobile Broadband capabilities has grown significantly in the past
- Demand increases in a faster scale with the innovations in Internet, applications and devices
- Research and innovations are crucial to satisfy the growing demand

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