Future 802.16 Networks: Challenges and Possibilities

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Future 802.16 Networks: Challenges and Possibilities

Agenda

- Motivation
- Objectives and Potential Requirements
- Advanced Access Networks
- Advanced Services
- Summary

Motivation

Drivers for future 802.16 Networks

- Market trends
- New usages

The Big Picture

Convergence of information & communications

Proliferation of applications and services

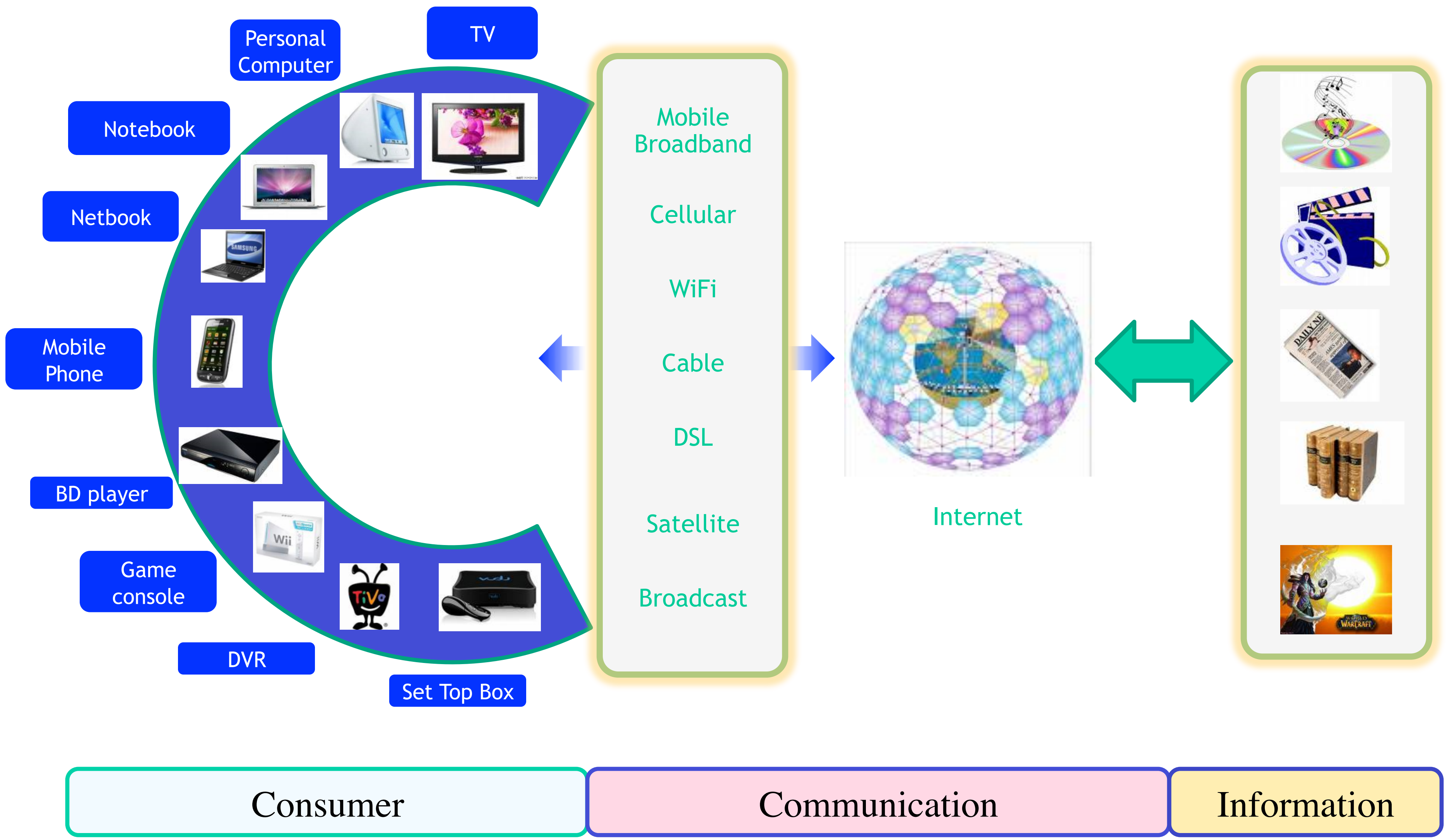
Diversification of connected devices

Integration of communication technologies

Explosion of wireless data traffic

Environment friendly ‘Green’ radios

Convergence of Information & Communications



Proliferation of Mobile Internet Apps & Services

+Logos and trademarks belong to the other entities
++ These are examples of applications & services

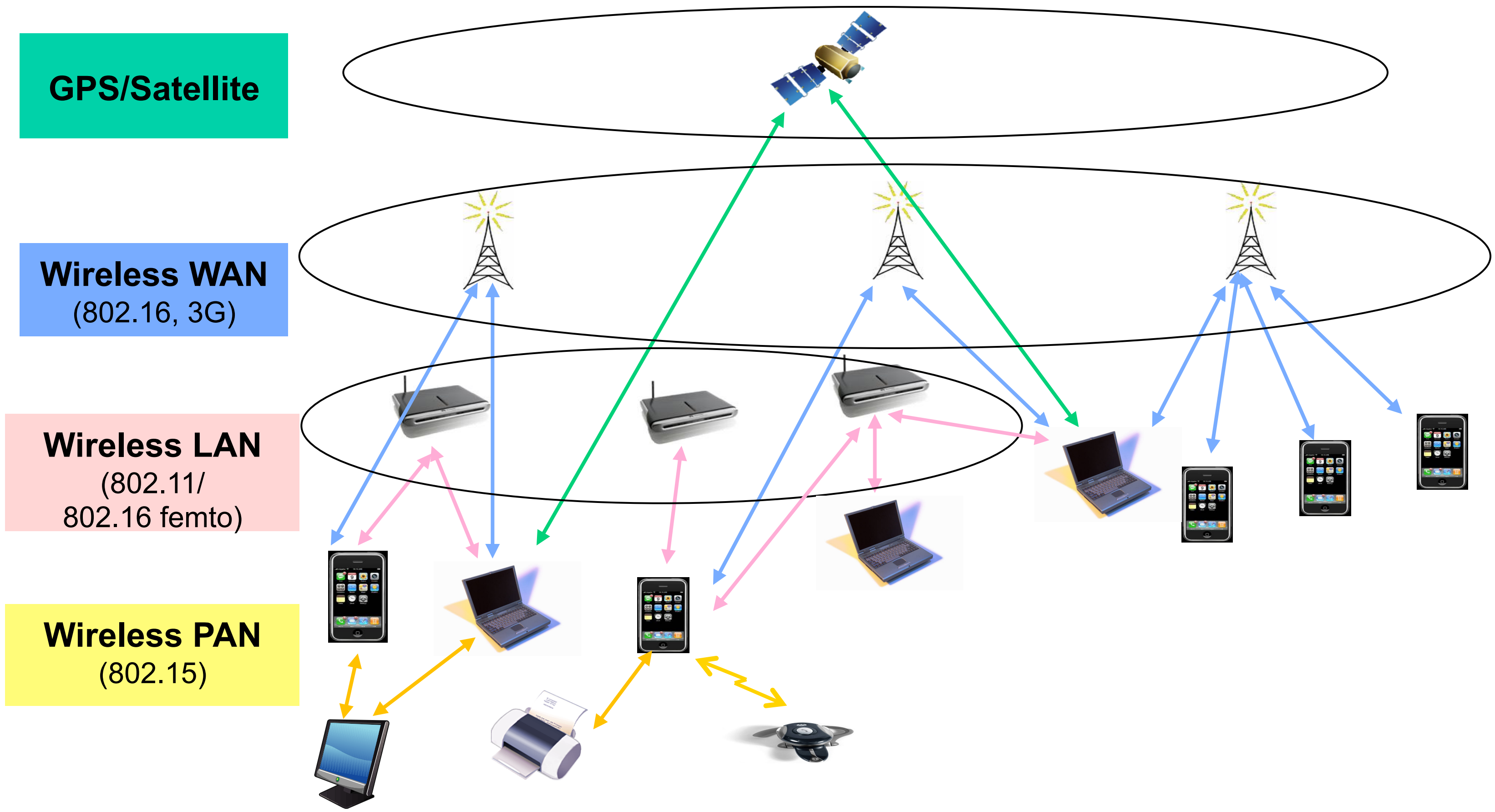
Diversification of connected devices

+Logos and trademarks belong to the other entities

++ These are examples of devices

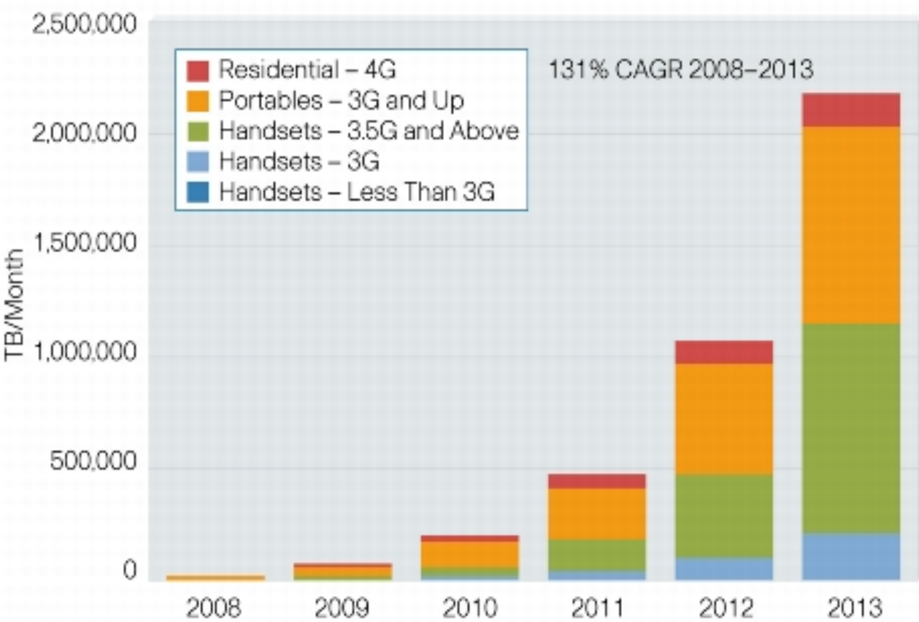
Integration of communication technologies

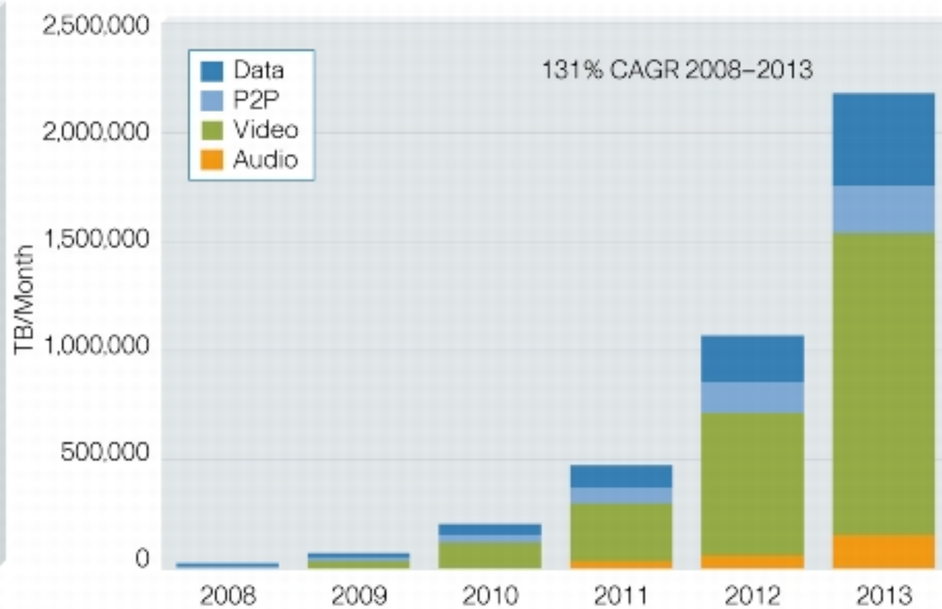
- Multiple radio access networks between information source and user
- Terminals implement multiple wireless interfaces and have varying capabilities



Explosion of Mobile data traffic

- Mobile data traffic is growing exponentially with introduction of new devices (ex. iPhone, Netbooks)
  - Larger screen mobile devices drive up data usage: (30 to 200x)
  - Video & data will be dominant sources of traffic
- Mobile data traffic is expected to grow by **66x** between 2008-2013 (Source: Cisco*)



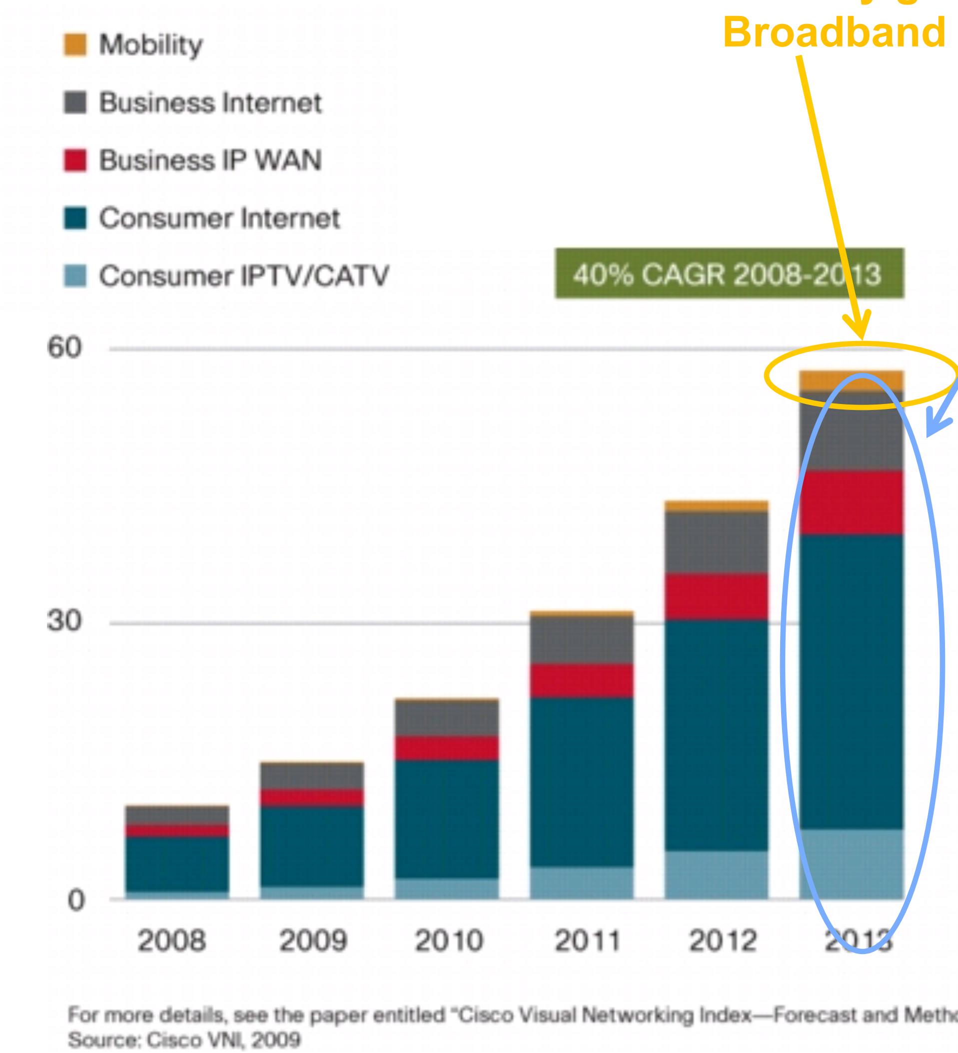


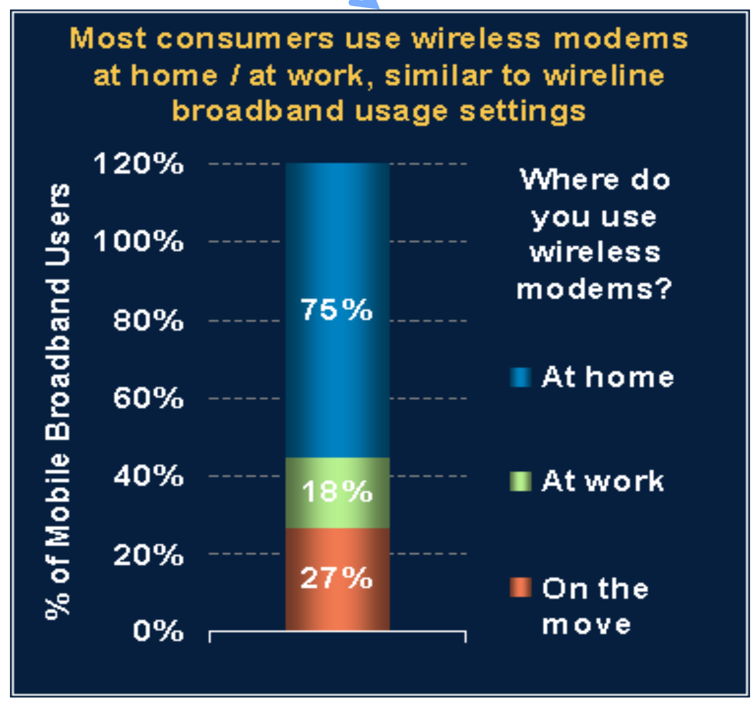
****Source: Cisco Visual Networking Index, Oct. 2009***

Mobility…But a small fraction of overall Broadband traffic

Mobility goes Broadband

Low mobility segment addressable by Future 802.16?





Source: Morgan Stanley Mobile Internet Report, December 2009

Environment-friendly Green radios

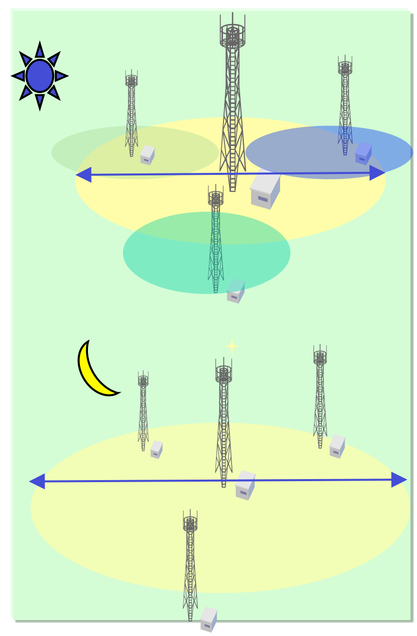
Consumer

Long Battery Life

Energy Saving Products

Network

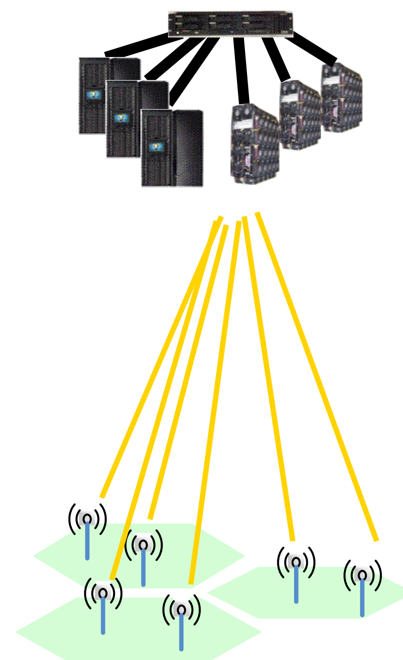
Reduced OPEX, Govt. Regulations



Protocols

Environmental

Low CO_2 & Radiation



Architectures

Objectives and Potential Requirements

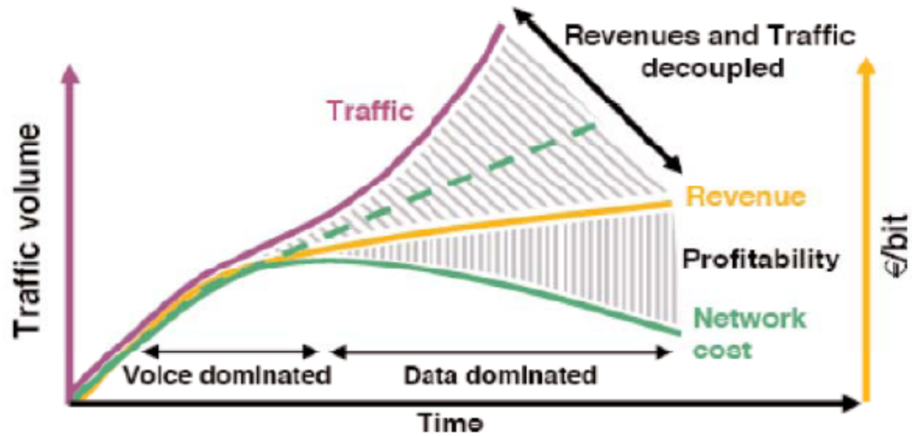
- Objectives
  - Enable Advanced Networks & Services
- Potential Requirements (and Technology possibilities)
  - Peak rate
  - System metrics
  - New metrics

Market developments present new Objectives

- Future networks should support explosive mobile data traffic growth driven by
  - Large screen devices
  - Multimedia applications
  - More connected users & devices
- Future networks should be optimized for mobile broadband traffic
  - Efficiently support low-mobility traffic
  - Efficiently support large number of mobile video users
  - Provide enhanced quality of experience for mobile internet applications
- Future networks should reduce operator costs
  - Low power consumption at BS (green)
  - Network deployments should require minimal planning and maintenance
- Future networks should interwork efficiently with other radio technologies
  - Converged multi-access networks
  - Multi-radio terminals

Challenge for Service Providers – Flat Revenues

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



- Service providers are facing challenges at two ends
  - Invest in network capacity to meet demand
  - Increase revenue with new applications and services

Future networks need to drastically lower Cost per Bit, and enable new Services

Service provider options

Ration Network Usage

- Tiered service levels
- Traffic shaping

Invest in Advanced Networks

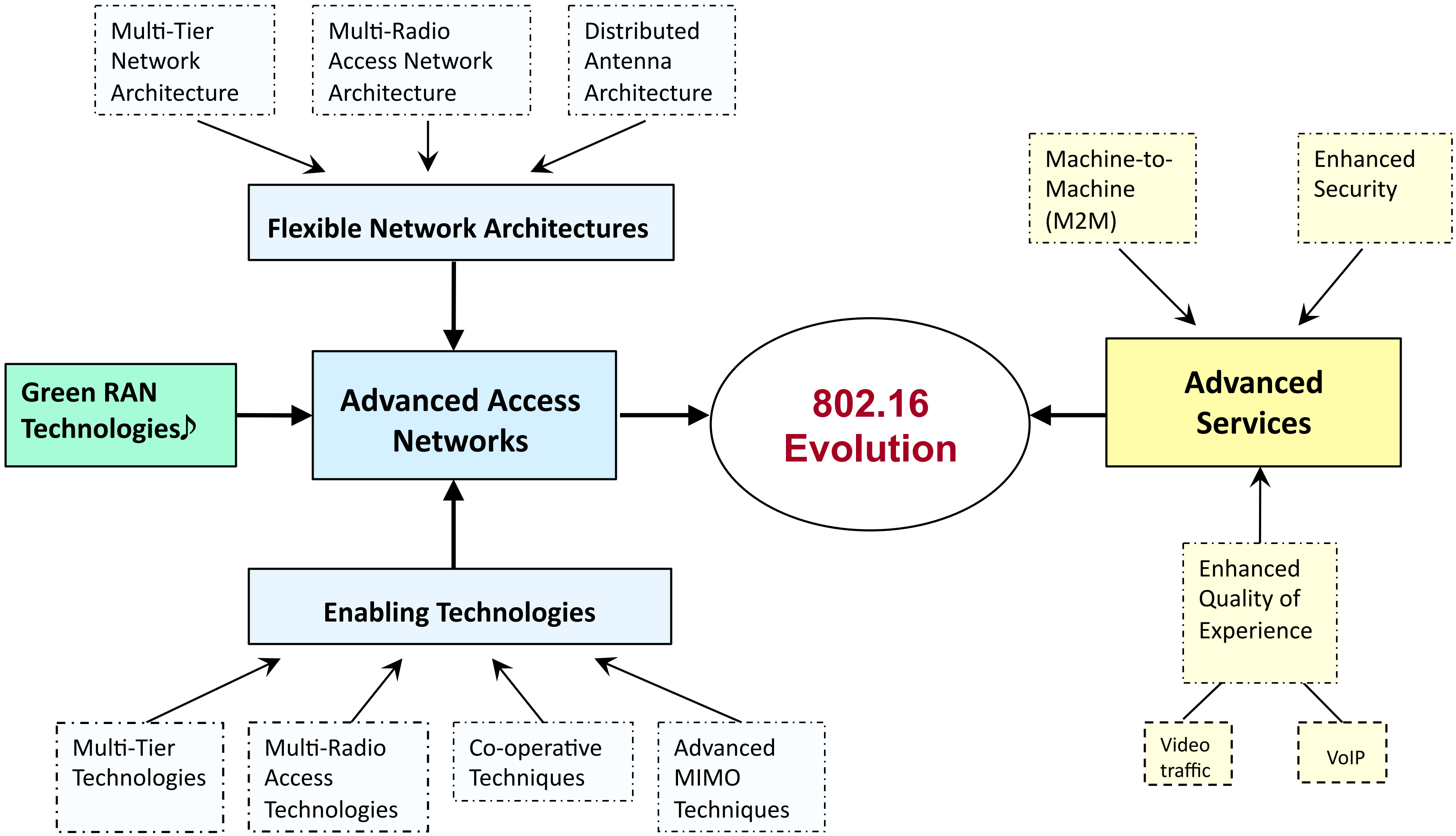
- High capacity
- Low cost
- Multi-radio access
- Green Radios

Create Advanced Services

- Enterprise Services
- Home broadband
- Enhanced QOE
- Enhanced Security
- M2M – new business

Focus of this presentation is Technologies for Advanced Networks & Services

Future 802.16 – Enabling Technologies



Objectives and Potential Requirements

- Objectives
  - Enable Advanced Networks & Services
- Potential Requirements (and Technology possibilities)
  - Peak rate
  - System metrics
  - New metrics

Peak Rate

LANs	Wireless LANs	Wireless MANs
IEEE 802.3 Standards*	**IEEE 802.11 Standards***	**IEEE 802.16 Standards***
	802.11b (2.4 GHz) 802.11g (2.4 GHz) 802.11a (5 GHz) 802.11n (2.4, 5 GHz)	802.16e (Licensed <6 GHz) P802.16m (Licensed <6 GHz) *(under development)*
ethernet alliance +	Wi Fi ALLIANCE + a b g Wi Fi n CERTIFIED +	WiMAX FORUM + WiMAX FORUM CERTIFIED +
Current Peak: 10Gbps	Current Peak: 600Mbps	Current Peak: 300Mbps
<u>Target Peak</u> IEEE P802.3ba : 40/100 Gbps	<u>Target Peak</u> IEEE P802.11ac (5GHz): >1 Gbps IEEE P802.11ad (60GHz):>1-3 Gbps	<u>Target Peak</u> 1-5 Gbps?

Peak Rates of 1-5 Gbps potential target for Wireless Broadband

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*Not a complete list of IEEE 802 standards

Potential Technologies to Achieve Peak Rate

Metric	Potential Target	Enabling Technologies
Peak Data Rate *(bps)*	• **1 to 5 Gbps** Baseline (16m) – ITU submission • Peak rate ~ 356 Mbps, 4x4 MIMO, 20MHz • Peak rate ~ 712 Mbps, 8x8 MIMO, 20MHz • Carrier Aggregation (100MHz) ~3.6 Gbps	**Higher BW support (40 MHz)** • Peak Rate ~ 16m rate x 2 = 1.4Gbps **Multi-Carrier, licensed & unlicensed** • Peak Rate ~ 1.4 Gbps x 4 carriers • 802.11 radio is used in conjunction with 802.16 **Improve Peak Spectral Efficiency (below)**
Peak Spectral Efficiency *(bps/Hz)*	• **Downlink: 45 bps/Hz** • **Uplink: 22 bps/Hz** [~ 3x IMT-advanced requirements] Baseline (16m) – ITU submission • DL Peak SE ~ 35.6 bps/Hz, 8 streams • UL Peak SE ~ 9.4 bps/Hz, 2 streams	**Higher order MIMO in UL (4 streams)** •UL Peak SE ~ 16m SE x 2 = 18.8 bps/Hz **Higher modulation (up to 256 QAM)** • DL Peak SE ~ 16m SE x (8/6) = 47.5 bps/Hz • UL Peak SE ~ 16m SE x (8/6) x 4 = 25 bps/Hz

System Metric Targets and Technologies

Metric	Potential Target	Enabling Technologies
Average SE *(bps/Hz/cell)*	• **Downlink > 2x with 4x4 (or 8x4)** • **Uplink > 2x with 4x4 (or 4x8)** Baseline (16m) ~ IMT-adv Requirements • DL Avg SE = 2.2 bps/Hz/sec, 4x2 • UL Avg SE = 1.4 bps/Hz/sec, 2x4 (Urban-coverage scenario)	**Advanced MIMO techniques** Ex. Distributed antennas • DL Avg SE ~ 3x with 4x4 **Multi-tier networks** Ex. Same Frequency Femtocell Network • Outdoor Avg SE ~ 1.5x (offload macro)
Cell-edge user SE *(bps/Hz/cell/ user)*	• **Downlink > 2x with 4x4 (or 8x4)** • **Uplink > 2x with 4x4 (or 4x8)** Baseline (16m) ~ IMT-adv Requirements • DL Cell-edge SE = 0.06 bps/Hz/sec, 4x2 • UL Cell-edge SE = 0.03 bps/Hz/sec, 2x4 (Urban-coverage scenario)	**Co-operative Techniques** Ex. Client collaboration • UL Cell-edge SE ~ 1.3 to 2x **Interference Mitigation Techniques**

New Metrics for Advanced Access Networks

Metric	Potential Target	Enabling Technologies
Areal Capacity *(bps/m^2)*	• Areal capacity = Sum throughput delivered by multiple network tiers / Coverage area • Areal capacity should be greater than single tier (macro) capacity	**Multi-radio access Networks**
		Multi-tier Femtocell Networks Ex. Same frequency Macro & Femto overlay • Areal Capacity ~ N_femto_APs x Avg SE x BW
		Multi-tier Relay Networks

New Metrics for Green Radio Networks

<table>
<tr><th>Metric</th><th>Potential Target</th><th>Enabling Technologies</th></tr>
<tr><td rowspan="3">Energy Efficiency*
(Joules/bit/user)

(Joules/bit/m^2)

(dB)

*typically implementation dependent</td><td rowspan="3">• Client Energy Efficiency: Energy consumed at Client /Traffic Transferred

• Network Energy Efficiency = Sum energy consumed by BS across network / Total traffic delivered / Coverage area

• Absolute Energy Efficiency = Relative metrics comparing energy-efficiency to theoretical Shannon limit</td><td>Power Management for Client (Sleep/Idle Durations)</td></tr>
<tr><td>Traffic Aware Power Savings in Network</td></tr>
<tr><td>Techniques to lower Transmit Power:

Advanced MIMO
Multi-tier Network Architectures
Multi-radio Network Architectures
Cooperative Techniques</td></tr>
</table>

Shannon's Limit:

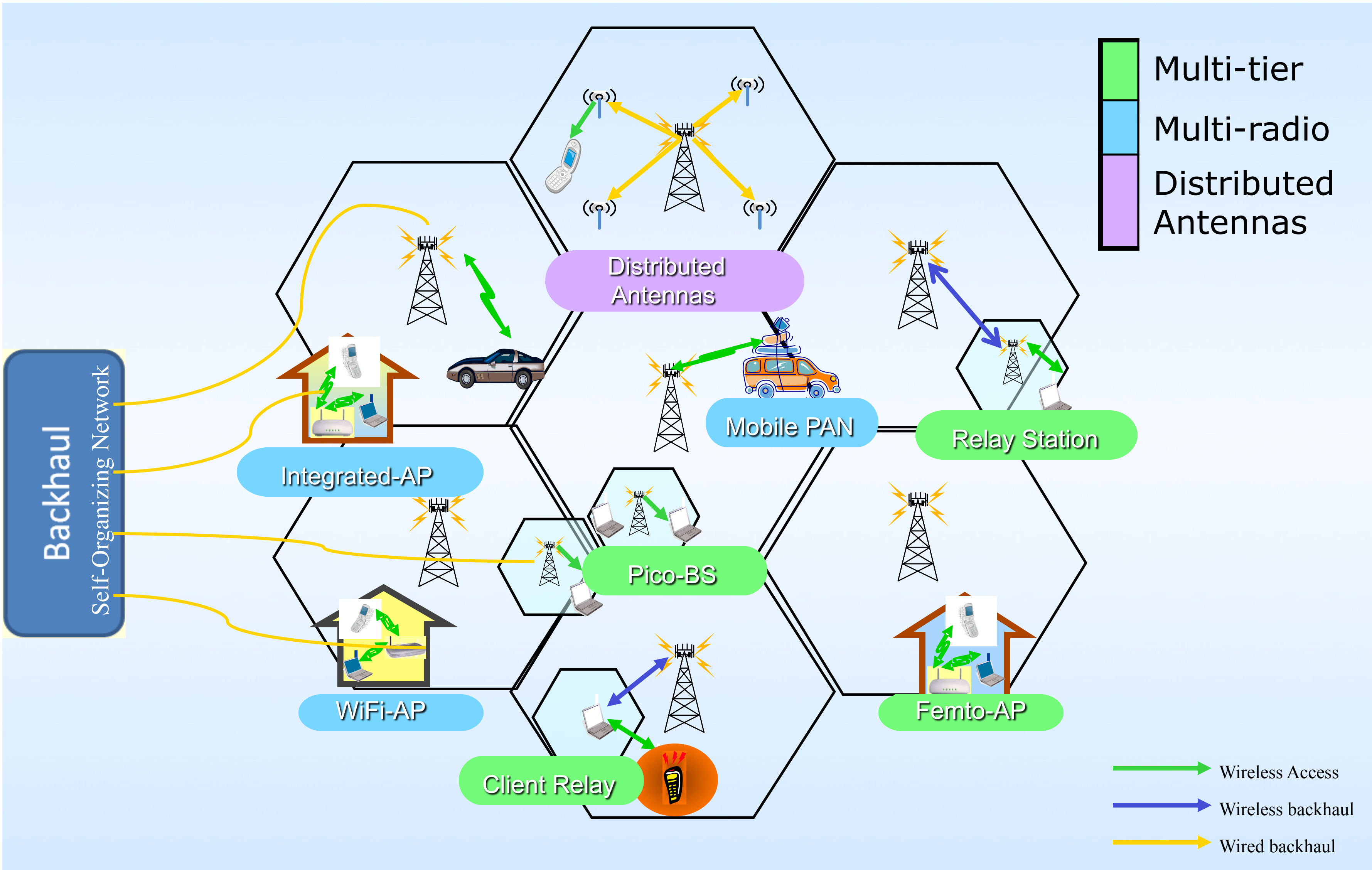
$$E_{b,\min} = kT\ln(2) \quad (Joule/bit)$$
$$= 2.87x10^{-12}\, nJ/bit$$

Advanced Access Networks

- Network Architecture
  - Multi-tier network architecture
  - Multi-radio access architecture
  - Distributed Antenna System (DAS) architecture

- Enabling Technologies
  - Multi-tier network technologies
  - Multi-access network technologies
  - Cooperative techniques
  - Advanced MIMO techniques
  - Traffic aware power savings

Vision of Advanced Access Network Architecture

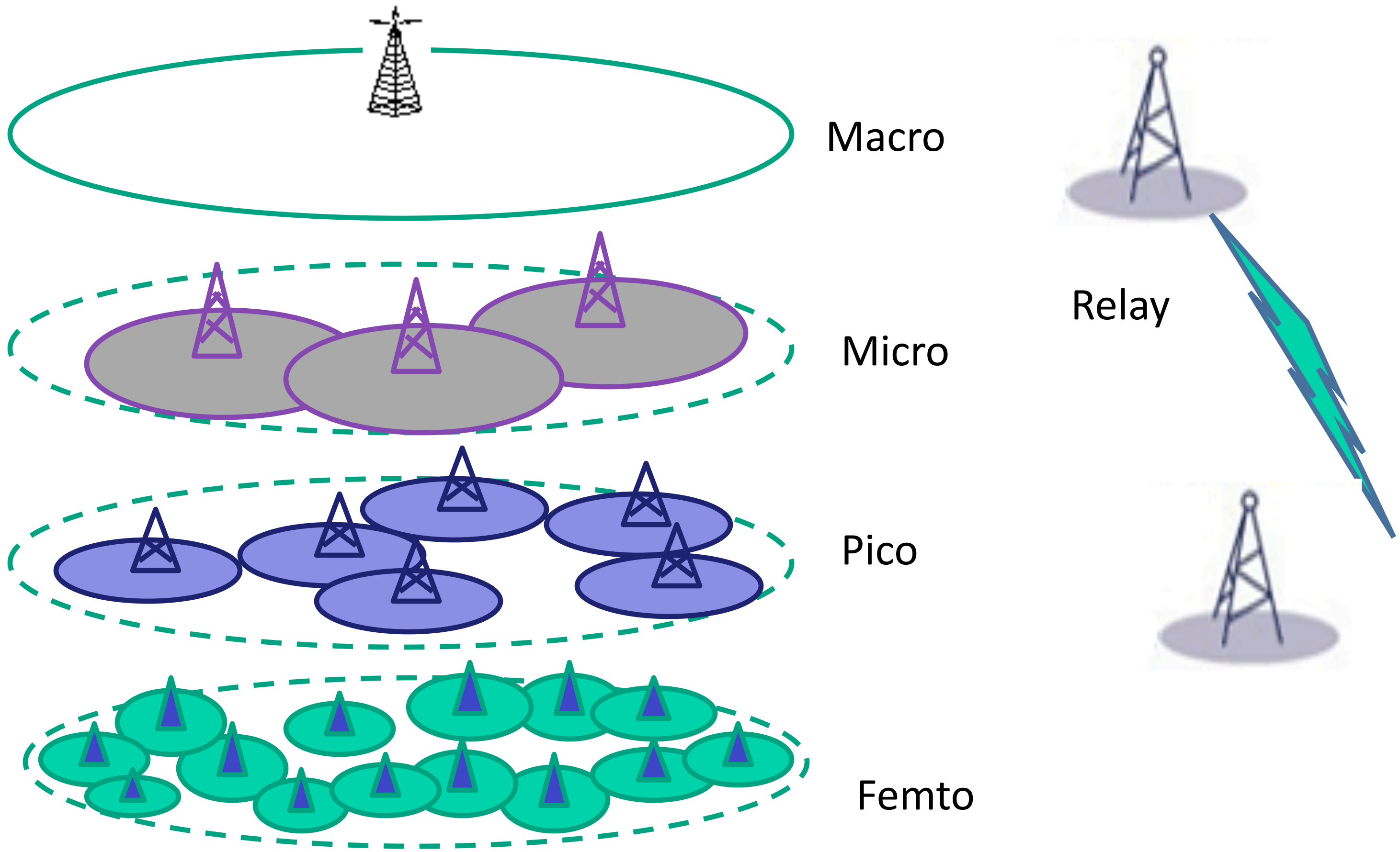


Enabling technologies for Multi-tier networks

Multi-tier Networks

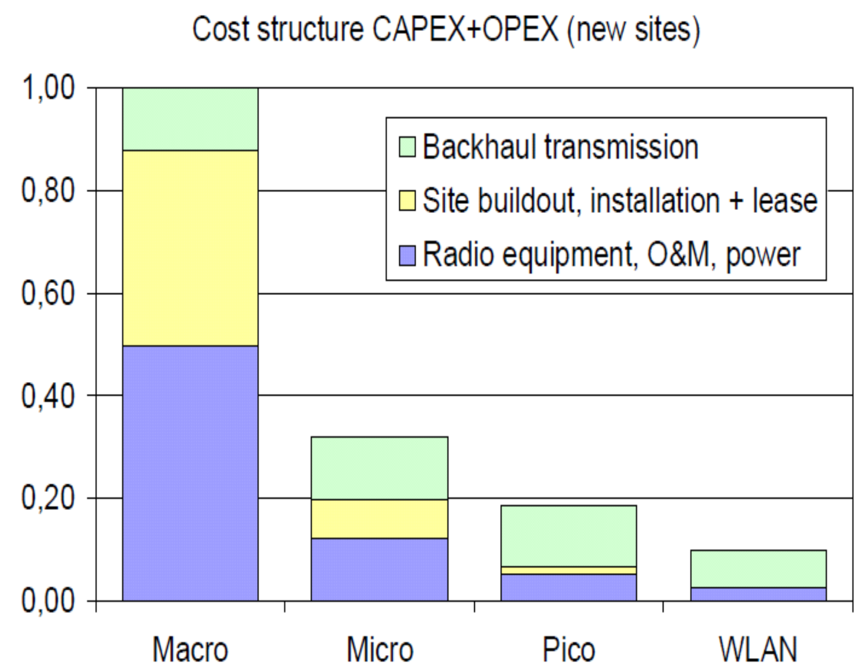
Aggressive Spectrum Utilization

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



Advantages of Multi-tier Networks

- Significant gains in areal capacity via aggressive spectrum reuse and use of unlicensed bands
  - E.g.: Co-channel femto-cells provide linear gains in areal capacity with increasing number of femto-AP's in a multi-tier deployment
- Cost structure of smaller cells (pico and femto) is more favorable
- Indoor coverage is improved through low cost femto-cells



Source: Johansson at al, 'A Methodology for Estimating Cost and Performance of Heterogeneous Wireless Access Networks', PIMRC'07.

Significant potential savings in **cost per bit** via multi-tier networks

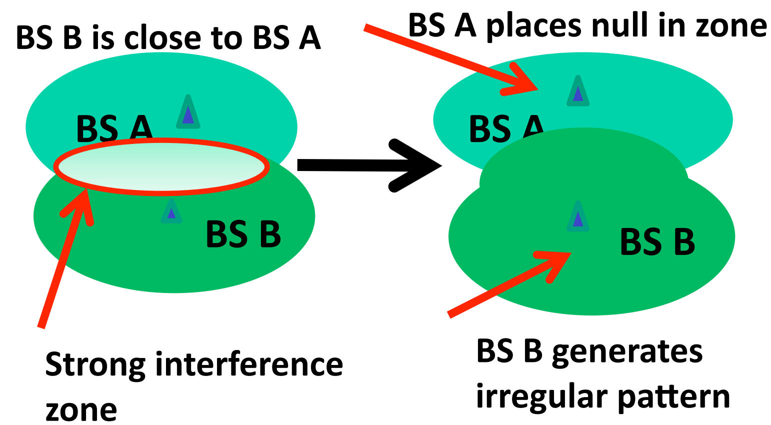
Inter-Tier Interference is a Challenge

- Example: Femto-cells interfere w/ macro-users and other femto-cells when reusing common spectrum
- Robust solutions are needed for control and data

Key Technologies

Interference Sensing w/ Cell Shaping

- Use of antenna arrays to place nulls in the direction of interfering neighbors

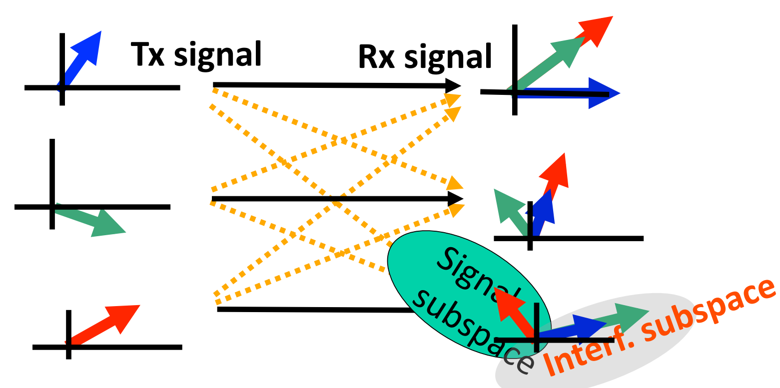


Advanced radio resource management

- Intelligent spectrum partitioning amongst tiers: fractional frequency reuse, femto free time-zoning, power control

Interference Alignment

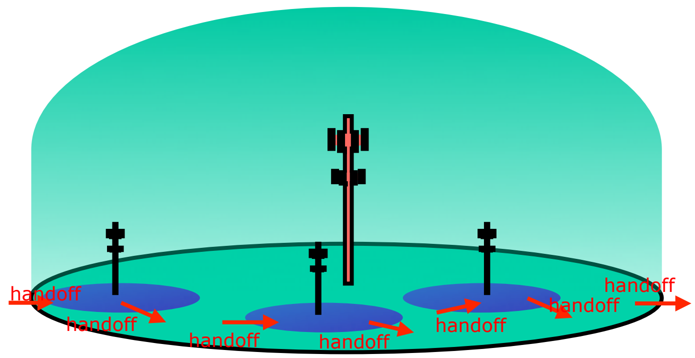
- Align transmit directions so that interfering signals is “contained” in one “direction” (subspace)



Mobility & Network Management is a Challenge

Intelligent Handoffs

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



Self Organization

- Self-organization and management across tiers required to maintain low OPEX and quick network response

New Network Elements

- Is there an optimum middle ground between consumer owned & deployed private femto-AP (low cost) versus operator owned & deployed public pico-BS?

Enabling technologies for Multi-radio access networks

Goals for Multi-Radio Access Interworking

Enhanced Spectrum Utilization

- Synergistic use of unlicensed bands with 802.16 (Virtual WiMAX Carrier)
- Use of 802.16 in unlicensed and lightly licensed spectrum

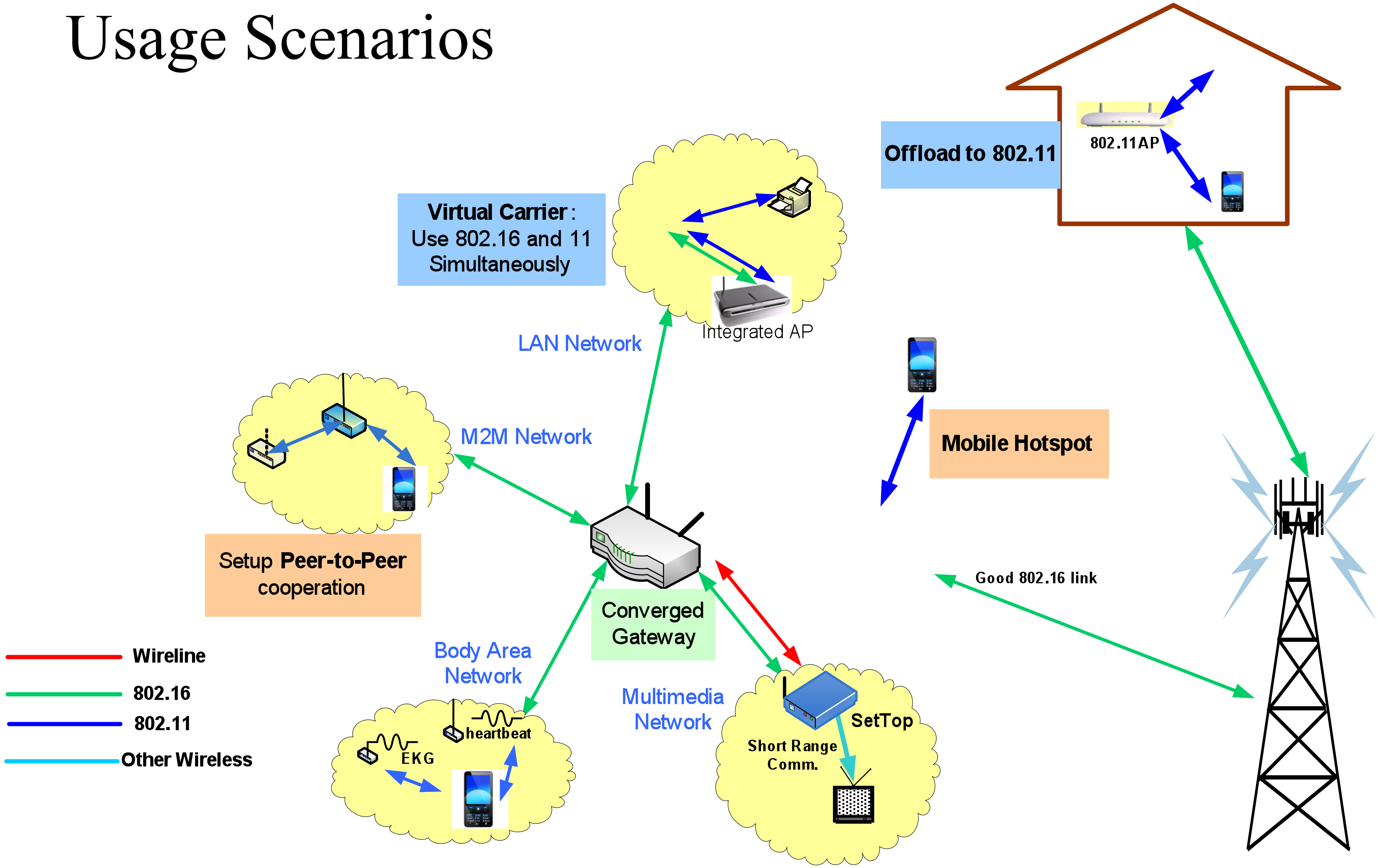
Manage Interworking of Multiple Radio Access Technologies with 802.16

- 802.16 provides control & management of multiple RATs (Converged Home)
- 802.16 enhances connectivity and cooperation for multi-radio devices (Mobile Hotspot)

Support Efficient Multi-Radio Operation at Subscriber terminal

- Address “multi-radio” and “single-radio” device implementations
- Protocol support to enable multi-radio integration

Usage Scenarios



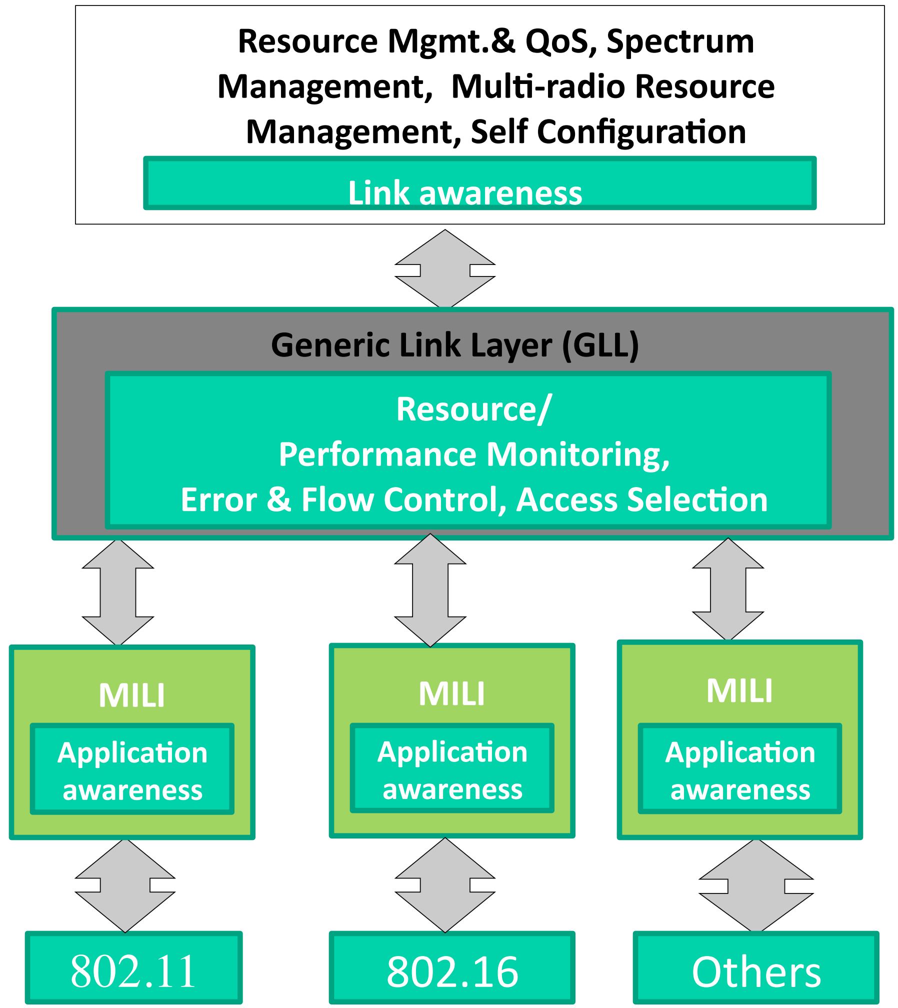
Home Converged Gateway coordinates transmissions and assists “capillary networks”

Potential Techniques and their Advantages

Idea	Interworking Techniques	Advantages
WiFi Off-Load	Handoff to WiFi	Throughput gains ~3x for indoor users
Virtual WiMAX carrier	• Carrier Aggregation • QoS/Load Balancing • Diversity /Redundancy • Reduced Control Overhead	• Peak throughput (~2-3x) • Enhanced QoS • SINR (~3-5 dB), Lower Latency • Higher System Throughput
Mobile Hotspot	Connect LAN/PAN devices to WAN	Improves connectivity, coverage
Management & control with 802.16	Control of in-home LAN/PAN/BAN interfaces, P2P connectivity	• Security • In-home services, automated configuration • Seamless operation across RATs
Multi-radio coexistence at Terminal	Protocols to support multi-radio integration	Efficient low-cost, low power devices
Multi-RAT co-existence at Network	Use of 802.16 to allow communication between RATs	Facilitates spectrum sharing in 'lightly licensed' bands, and multi-radio implementation

Key Challenges for Network and Protocols

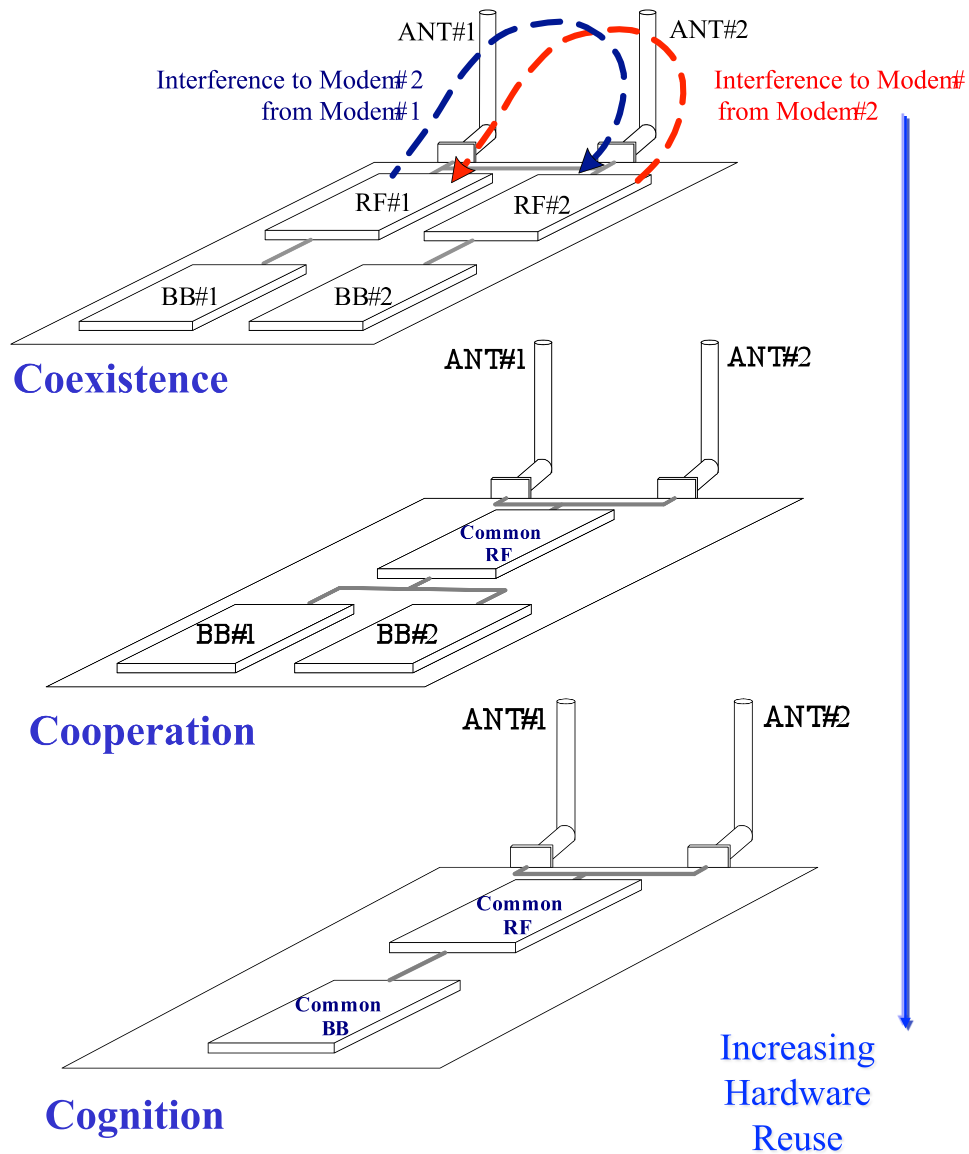
- Determine interworking layer: IP, MAC or PHY Layer?
- Address distributed, centralized and co-located multi-radio network interfaces
- Define interworking functions and protocols (e.g. Generic link layer, Multi-radio resource management)
- Measurements & reporting for application/link layer awareness across protocol stack
- Coexistence of heterogeneous RATs in unlicensed or lightly licensed spectrum



*MILI=Media Independent Link Interface

Key Challenges for Devices

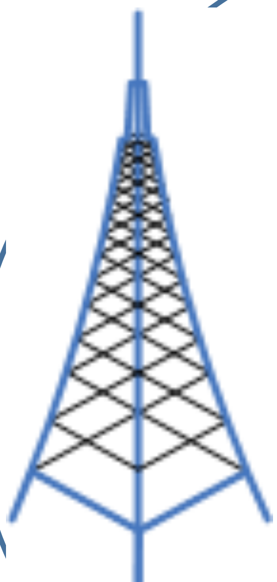
- Interworking to address a mix of multi-radio and single radio devices
- Higher integration at network level can lead to better multi-radio integration in terminal
- Protocol support may be needed for
  - **Coexistence**: Managing interference across co-located radio transceivers
  - **Cooperation**: Managing interworking across multiple transceivers when hardware is shared
  - **Cognition**: Intelligent use of spectrum resources available in network with fully integrated hardware



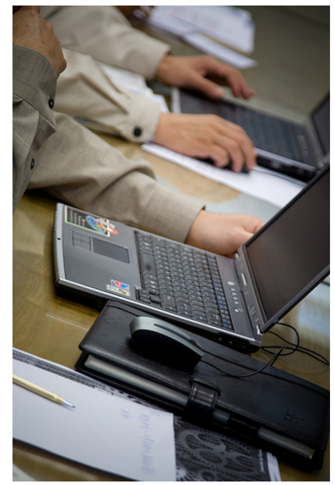
Cooperative techniques

We live and work in clusters

Most devices have more than one type of connectivity
Most users are nomadic/stationary ♪



Coffee shops

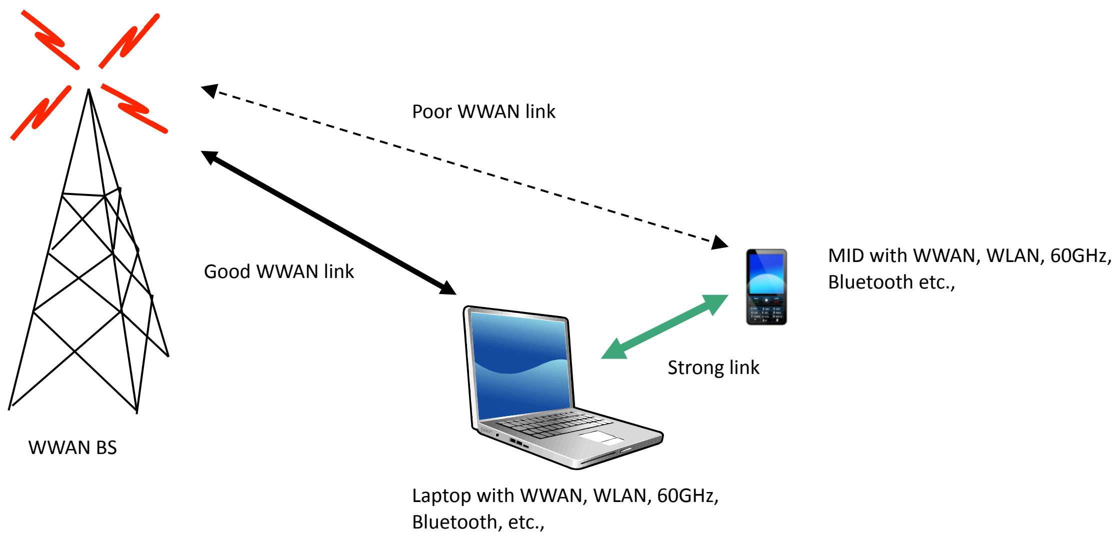


Meetings / Offices

Class rooms

Can we leverage this clustering to offer better end-user experience?

Client Collaboration



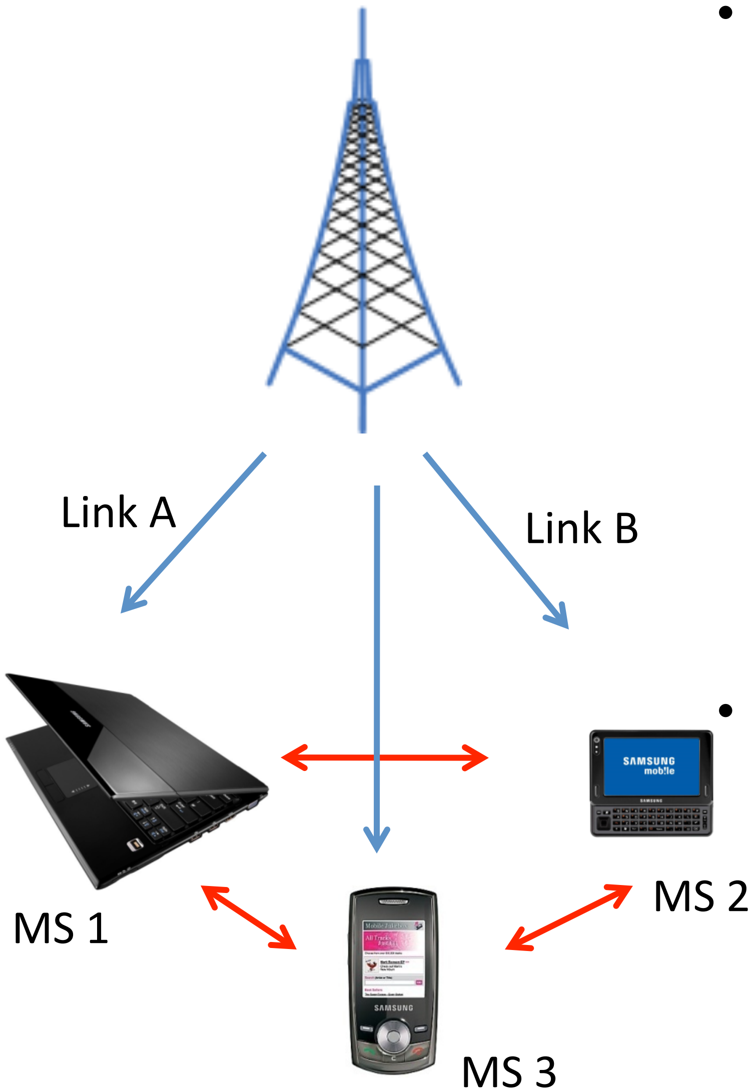
Client Collaboration is a technique where clients interact to jointly transmit and/or receive information in wireless environments.

Idea: Exploit client clustering and peer-to-peer communication to transmit/receive information over multiple paths between BS and client

Benefits:

1) Faster over the air ⇒ improved "cell-edge" rates without increase in infrastructure cost
2) Less interference ⇒ increased system capacity
3) Lower power transmission ⇒ extend battery of clients with poor channels

Enabling Client Collaboration



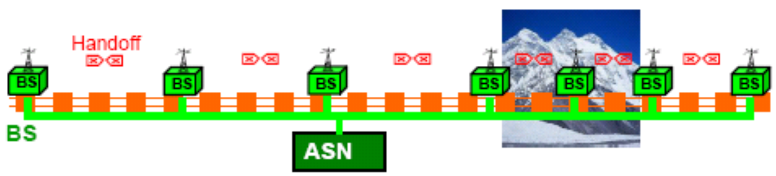
- Enablers needed to take advantage of client clustering
  - How to discover neighbors?
  - How is neighbor discovery/cluster formation conveyed to the 16x BS?
    - Who acts as the leader/coordinator of the cluster?
    - Who talks to the BS?
  - How to size these clusters?
  - How does the macro act on this cluster and signal data meant for any member(s) of the cluster?
  - If in-band signaling is used, which relaying scheme to use?
- Efficient signaling support is crucial and necessary

Advanced MIMO techniques

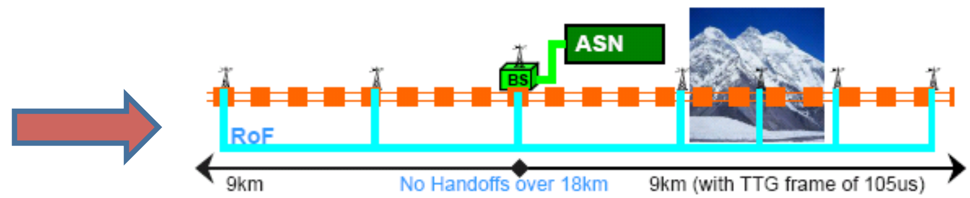
Distributed Antenna System (DAS)

- Definition: DAS is a network of spatially separated antennas called "nodes", connected to a common source via a transport medium, that provides wireless service within a geographic area or structure

- Example: WiMAX train field trial-Application of 802.16e to Taiwan High Speed Rail Bullet train system. (~300km/h)

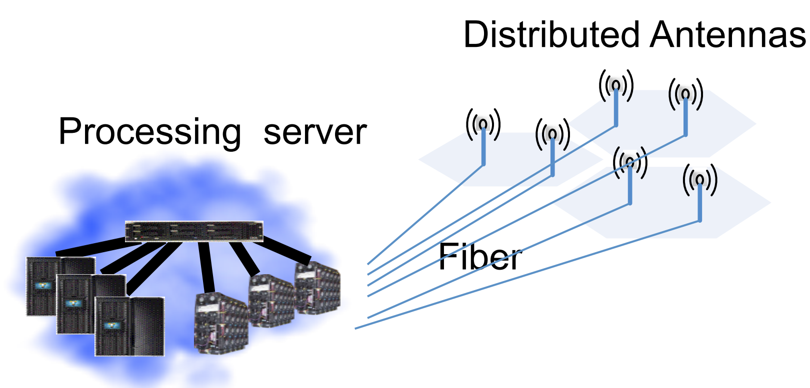


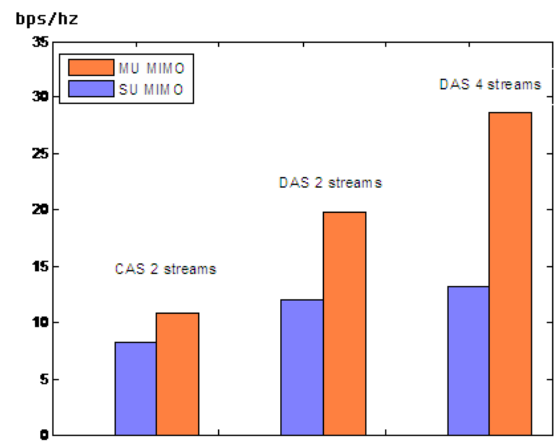
Traditional area coverage approach



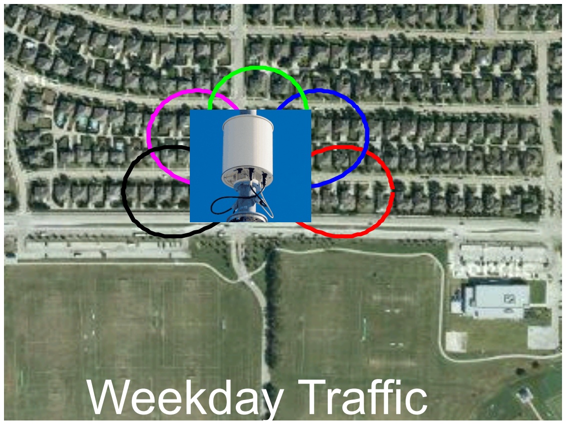
Radio-over-fiber distributed antenna system approach

- Benefits : DAS with 4 distributed antennas show nearly 300% gain over CAS by utilizing MU MIMO protocol in system evaluation



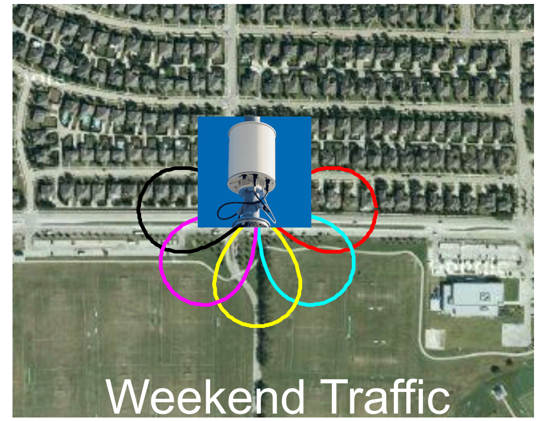


Dynamic Beam-Forming♪



Use of higher-dimensional antenna arrays to provide

- ➢ Arbitrary sectorization ➔ Simple deployment
- ➢ Real-time response to non-homogenous traffic
- ➢ High beam gains ➔ Lower transmit power (Green)
- ➢ Interference nulling ➔ Higher system capacity



Capacity-Enhancing MIMO Techniques♪

- Key use case: Low-speed terminals ➔ Slowly varying channels
- Slowly varying channels ➔ Enables detailed channel feedback
- Detailed channel feedback enables
  - ➢ SVD beam-forming
  - ➢ "Water-pouring"
  - ➢ Efficient high-order MU-MIMO

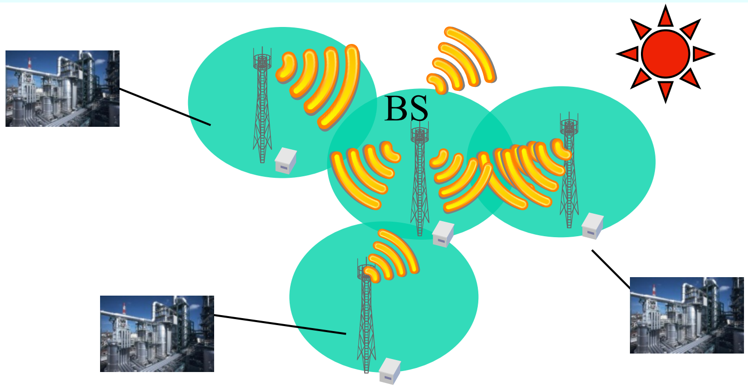
Advanced MIMO Techniques - Challenges

- Distributed Antenna Systems
  - Antenna selection & channel measurement
  - Multiple antenna node cooperation
  - Handover across antenna nodes within a cell
  - Interference management among nodes
  - Uplink power control with multiple nodes
- Dynamic Beam-Forming
  - Feedback to enable dynamic beam selection
  - Interference sensing mechanisms
  - Highly-accurate antenna array calibration
- Capacity Enhancing MIMO
  - Detailed channel feedback

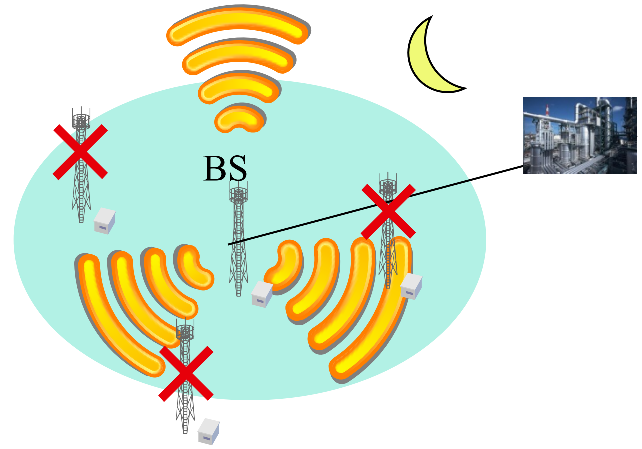
Traffic aware power savings

Coverage and neighbor cell list adjustment in self-organizing network

Daytime: High traffic, 4 base stations



Off-peak time: Low traffic, 1 base station



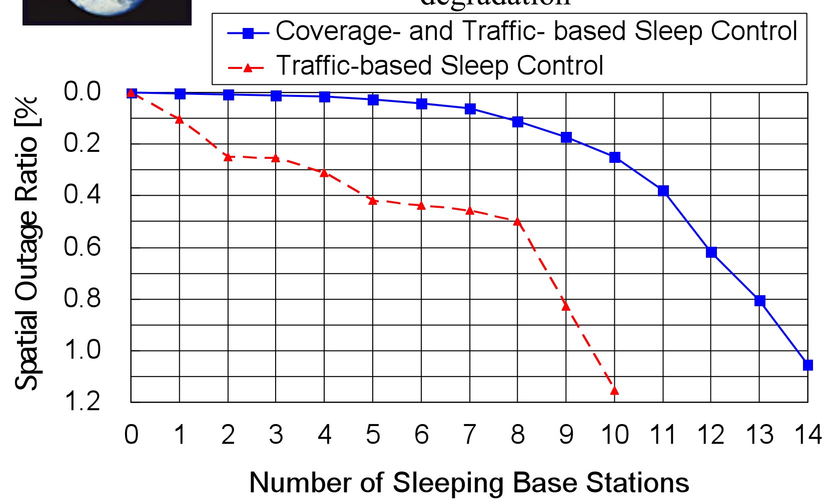
Management → **Operation** → **Outcome**

Traffic Load
Coverage

→ Minimum use of base station

→ CO2 reduction
→ Power saving
→ Automated Operation

Case Study Example of Achievable Energy Saving without Network Performance degradation



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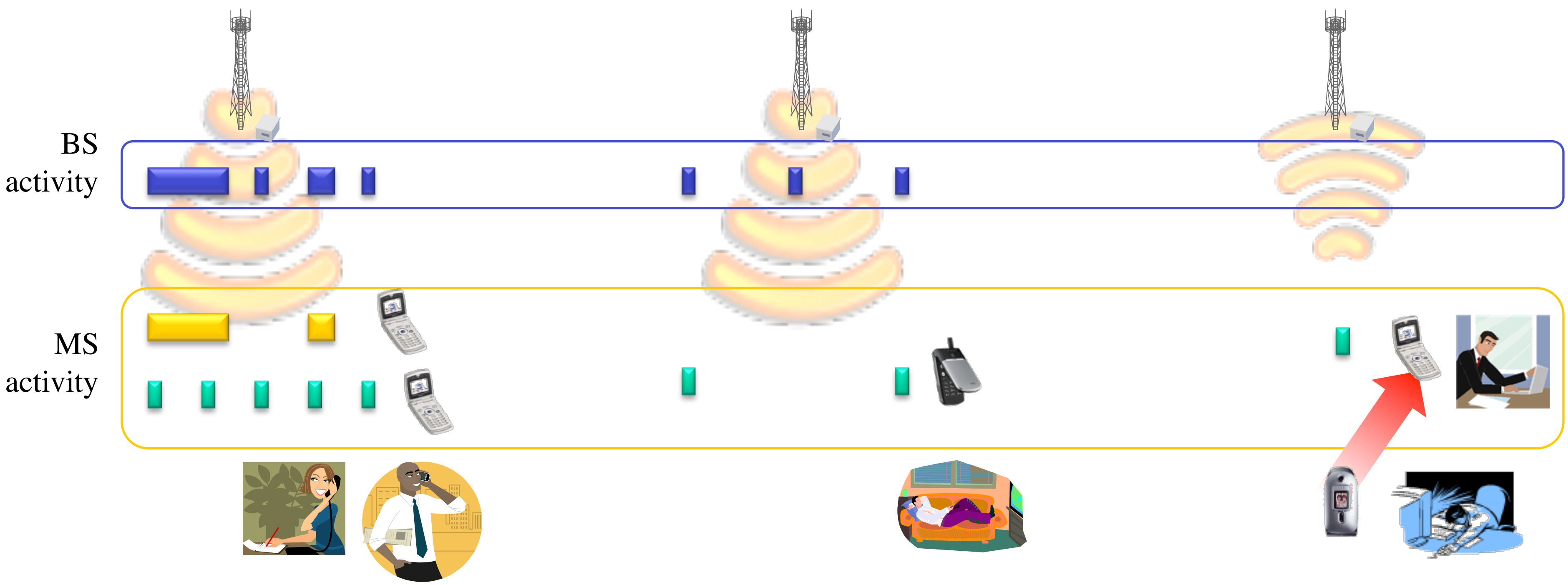
Dynamic Traffic-Aware Power Management Schemes

Active scenario	Idle scenario	Monitoring scenario
Adaptive low-duty cycles	Static low-duty cycles	Hibernation
"transmit only when necessary"	Guarantee responsiveness and availability with minimal power footprint	Passive monitoring for fast recovery



Advanced Services

- Machine-to-Machine communications
- Enhanced Quality of Experience for voice & video
- Enhancements for Security

Machine-to-Machine communications (M2M)

M2M – What is it?

Definition:

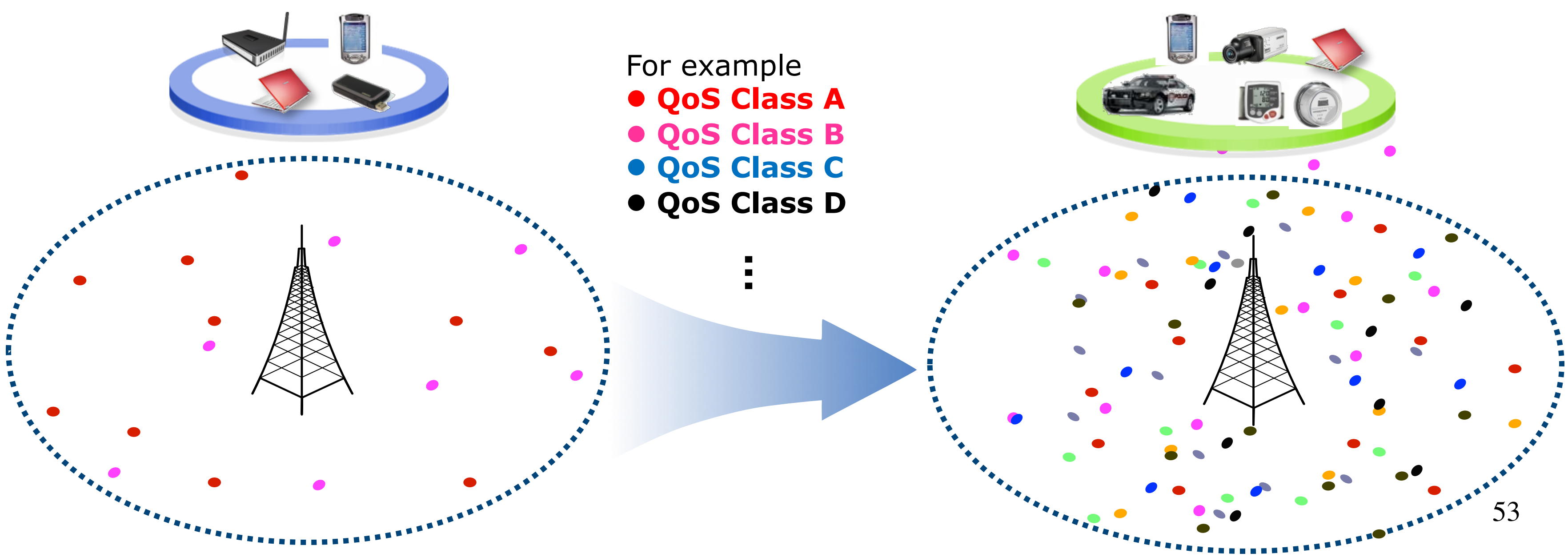
- Data communication between devices or device and server that may not req uire human interaction

Characteristics:

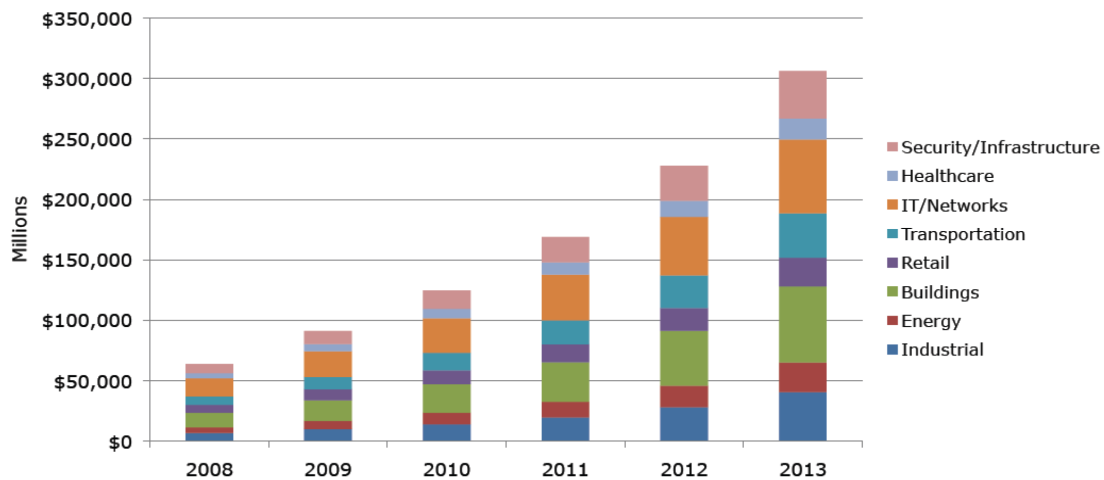
- Different business scenarios
- Potentially very large number of devices
  - Small bursts per M2M device
  - Device-originated connectivity
  - Larger percentage of uplink traffic
- Lower cost and energy for M2M devices
- Coexistence with other RFs in neighboring M2M network

M2M Service Area

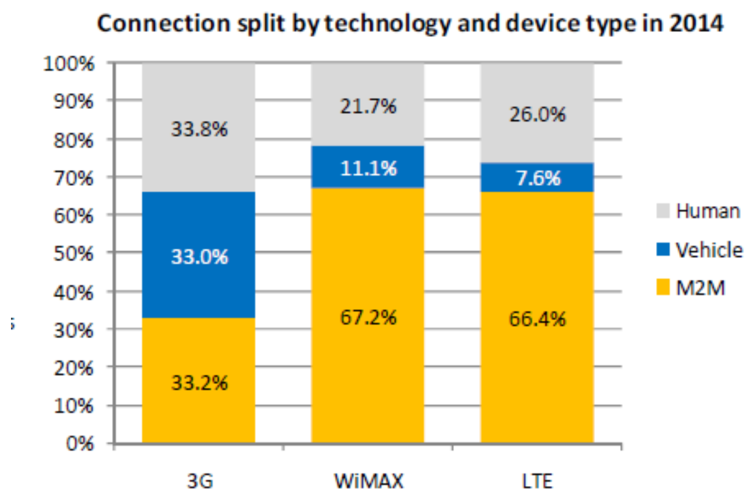
Service Area♪	M2M apps w/use cases requiring WAN range
Security & Public Safety	Surveillance systems, Control of physical access (e.g. to building), Car/driver Security♪
Tracking & Tracing♪	Fleet management, Order management, Pay as you drive, Asset Tracking, Navigation, Traffic Info, Tolls
Payment♪	Point of sales, Vending machines, Gaming machines
Healthcare♪	Monitoring vital signs, Supporting the aged or handicapped Web access telemedicine points, Remote diagnostics♪
Remote Maintenance/Control♪	Sensors, Lighting, Pumps, Valves, Elevator control, Vending machine control, Vehicle diagnostics♪
Metering (ex. Smart Grid)♪	Power, Gas, Water, Heating, Grid control, Industrial metering♪
Consumer Devices♪	Digital photo frame, Digital camera, eBook♪



M2M Market



*** Harbor Research (2009)***



*** SENZT FILI Report (2008)***

Key M2M Features and Standards Impact

Features	M2M Apps	Standards Changes							
		M2M Coop. & Comm.	Sleep & Idle Mode	Mobility Mgmt	Link Adaptation	Burst Mgmt, BW Request & Allocation	HARQ & ARQ	Frame Structure & Zoning	Network Entry
Extremely low power	Metering Tracking Health Remote Maint & Ctrl	√	√	√	√	√			
High Reliability	Security Metering Health Remote Maint & Ctrl	√	√	√	√	√	√	√	
Access Priority	Health Remote Maint & Ctrl		√			√	√	√	
Active QoS Maintenance	Consumer Equipment	√			√	√			
Mass device transmission	Security Metering Tracking Health	√			√	√	√	√	√

Enhanced Quality of Experience (QOE) for voice & video

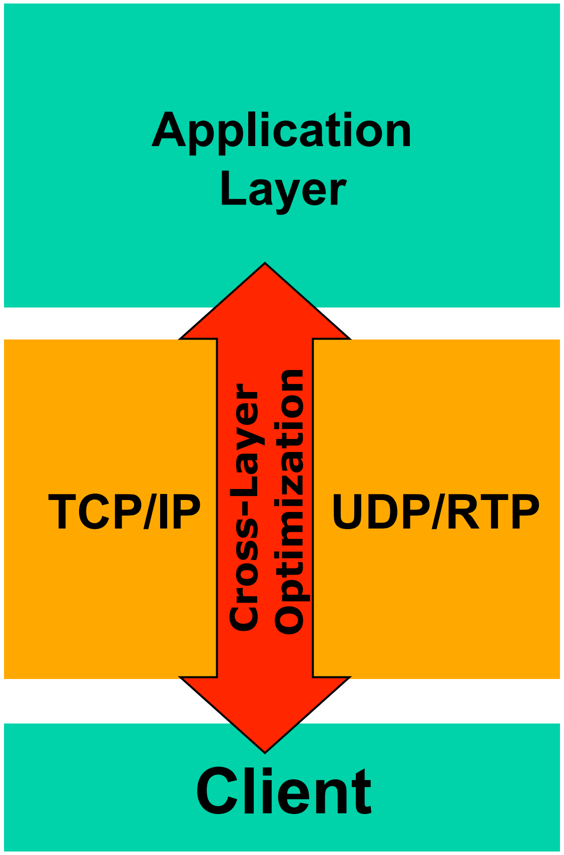
Enhancing QoE – Motivation and Objectives

- **<u>Many Devices/Applications Require Enhanced QoE:</u>**
  - Expect large number of heterogeneous mobile internet devices with various applications requiring a range of quality of experience (QoE) metrics.
  - Example: Smartphone/Netbook supporting apps such as social networking (twitter, chat, facebook, etc.), Skype, browsing, video conferencing, streaming, IPTV
  - Example QoE Metrics of Interest: MOS for voice, distortion/VQM for video, etc.
- **<u>Limitations of Today's QoS Approach</u>**
  - Not straightforward to map today's QoS parameters to user experience
  - Lack of cost effective solutions for current/future Internet Apps
  - No QoS mechanisms for best effort (BE) service class
- **<u>Objectives:</u>**
  - Enable QoE-driven radio and network optimization
  - Increase number of simultaneous users for mobile voice and video services while maintaining QoE for different internet applications
  - Ensure network adaptability and scalability to support
    - time-varying performance requirements due to changing network environment and various application implementations
    - dynamic traffic characteristics
    - multiple device classes

Enhancing QoE – Technology Enablers

- Cross-layer awareness to enable ecosystem to provide the desired QoE enhancements. Some examples:
  - Joint source-channel coding to improve video quality
  - 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

- QoE for voice and video communications should be optimized over advanced network architectures such as:
  - Heterogeneous networks (e.g., WiFi-assisted WAN, hybrid broadband/broadcast)
  - Multi-hop relay and femto-cell architectures
  - Multi-tier network architectures
  - Dense networks with large number of devices and applications



Enhancing QoE - Recommendations

- Define new system requirements for Mobile Internet - voice and video services, e.g., minimum number of video users, etc.

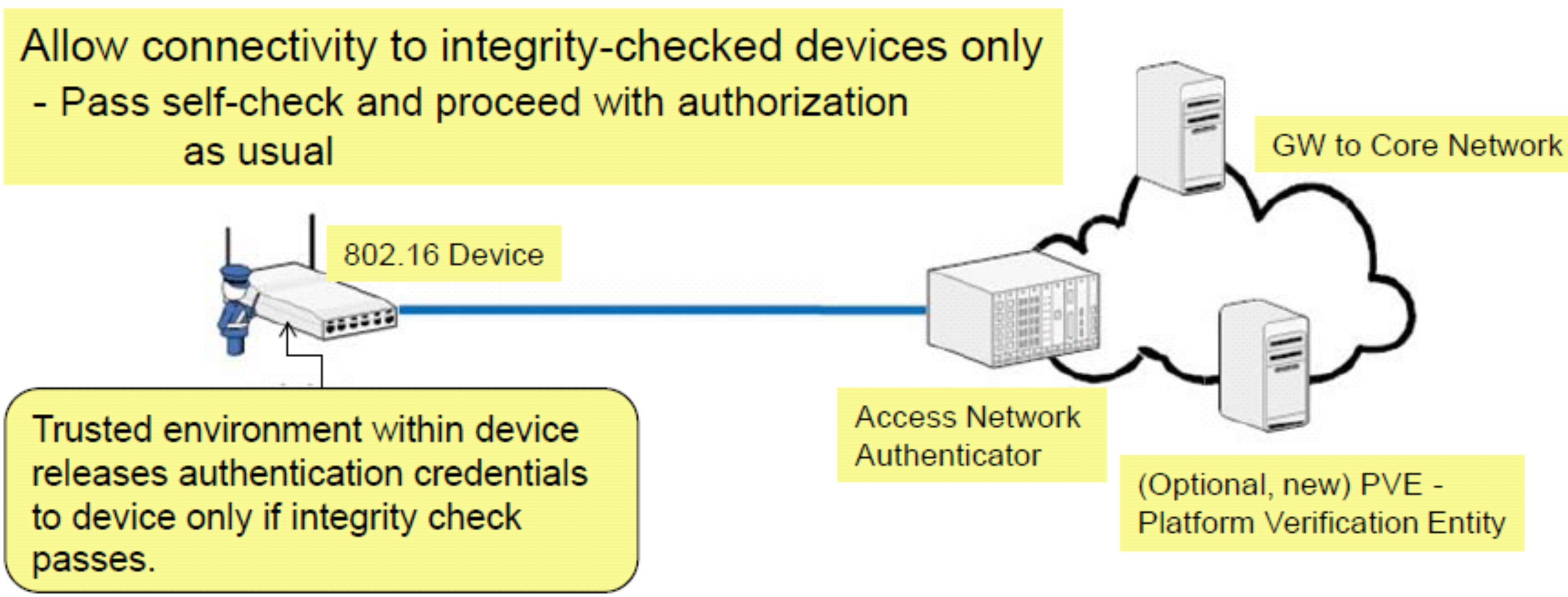
- Develop new air-interface specifications to meet target requirements for user QoE. The standard hooks are needed
  - To exchange application level information for better radio/network adaptation and resource management
  - To exchange radio/network level information for better application adaptation
  - To enable standard mechanisms to support QoE-aware adaptation and resource management for multiple flows

Enhancements for Security

Enhanced Security

Strong Authentication backed up by Device Integrity

- Evolution towards a large and growing number of devices outside of a firewall allows easy opportunity for physical tampering or illegal SW download
- Device integrity check complements existing authentication methods



Summary and Recommendations

In Summary - Key Technical Features

- Very high Peak throughput (> 1Gbps)
  - Support for bandwidths greater than 20MHz
- Advanced Access Networks
  - New flexible network architectures
  - Low cost deployments
  - Enabling technologies providing
    - Higher Spectral Efficiency (> 2x)
    - High Areal Capacity
    - Improved Energy Efficiency
- Advanced Services
  - Enhancements for video, voice & security
  - Support for new M2M service

Call for Interest Summary

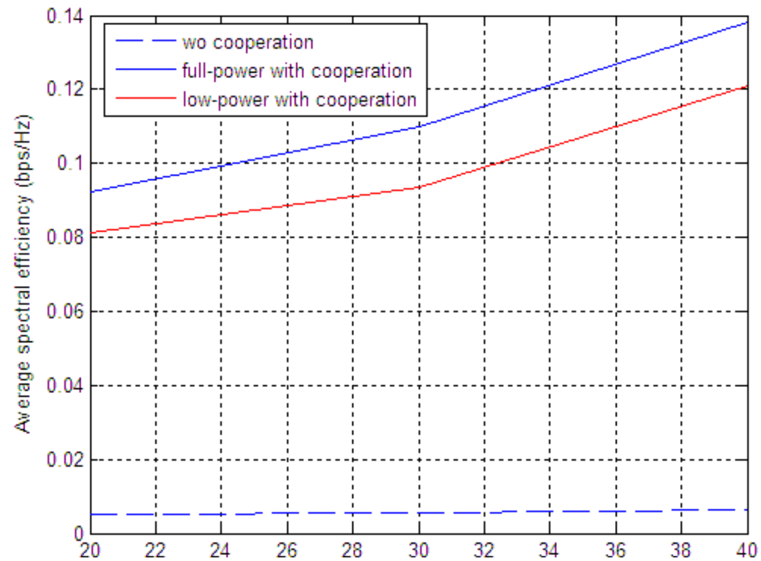
- Plan to initiate study for the following topics in 802.16 Working Group
  - Advanced Access Networks: Architectures (*ex. Multi-Tier, Multi-radio Access, Distributed Antennas*), and Enabling Technologies (*ex. Multi-tier network technologies, Multi-access network technologies, Cooperative techniques, Advanced MIMO techniques, Traffic aware power savings*)
  - Advanced Services: M2M, Improved QoE, Security
- Plan to initiate collaboration on studying some of these topics with other 802 Working Groups
  - 802.11 – WiFi offload, unlicensed spectrum utilization, interworking
  - 802.21 – Flexible protocols for interworking of multi-radio interfaces
  - 802.15 – Interworking in converged home scenario
  - 802 Emergency Services ECSG
- Plan to conduct study of these topics together towards identifying near term and long term projects in 802.16
- Plan to initiate one or more PARs for some of these topics in 2010
- We hope interested individuals will join this effort to help define the evolution of IEEE 802.16 standards based networks

Backup

Average Spectral & Energy Efficiency

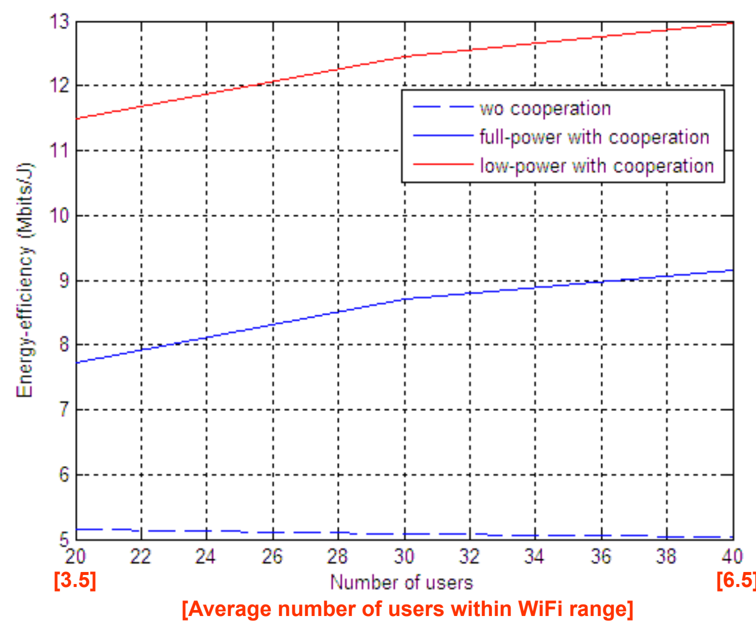
Client Cooperation significantly improves cell-edge rates

- Small clusters of clients (<6) suffice for large gains
- Full-power cooperation outperforms low-power cooperation
- Gains decrease with increased channel correlation among clients



Client Cooperation decreases total network energy consumption

- Originating AMS conserves energy by requiring fewer retransmissions and enabling higher MCS
- Cooperator consumes energy, but net result is energy savings
- Extends battery of clients w/ poor channels

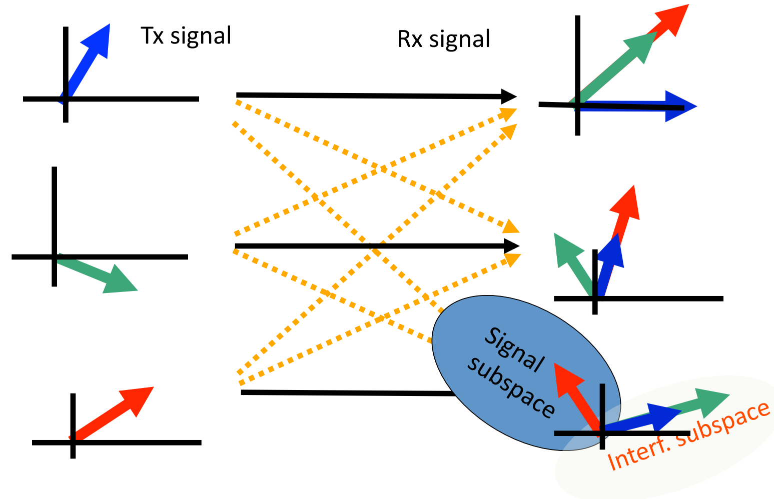


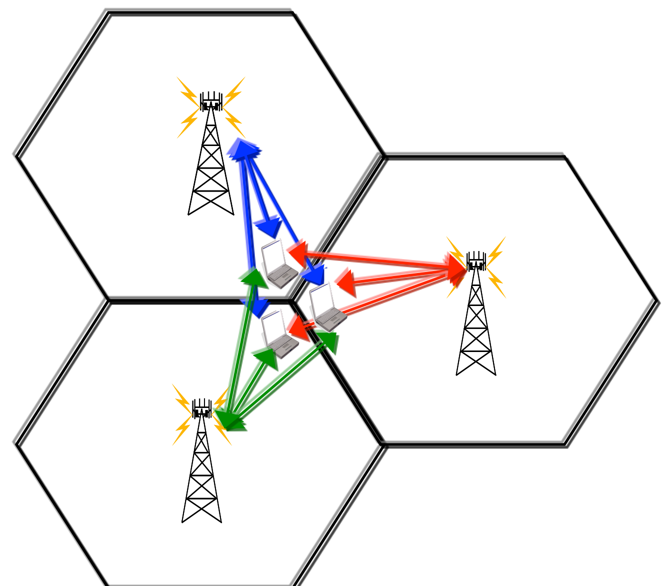
Interference Alignment

Idea

- Align transmit directions so that interfering signals all come from the same “direction” (subspace)
- Alignment can be across antennas, frequency, time
- Benefits: Improves uplink and downlink transmissions of cell-edge users;

  Low receiver complexity
- Challenge: Practical schemes that can achieve theoretical gain





Performance (theory) in high SNR regime: If there are K pairs and each node has M antennas, then KM/2 degrees of freedom are achievable. For comparison, perfect resource sharing achieves 1 degree of freedom. (Cadambe & Jafar 2008)

New Metrics for Green Networks

Examples

Theoretical minimum energy to receive an information bit reliably (Shannon's Law)

$$E_{b,\min} = kT\ln(2) \quad (Joule/bit)$$
$$= 2.87x10^{-12} nJ/bit$$

User Metrics

Total energy consumed by MS /Total Bits (Joules/bit)

Network Metrics

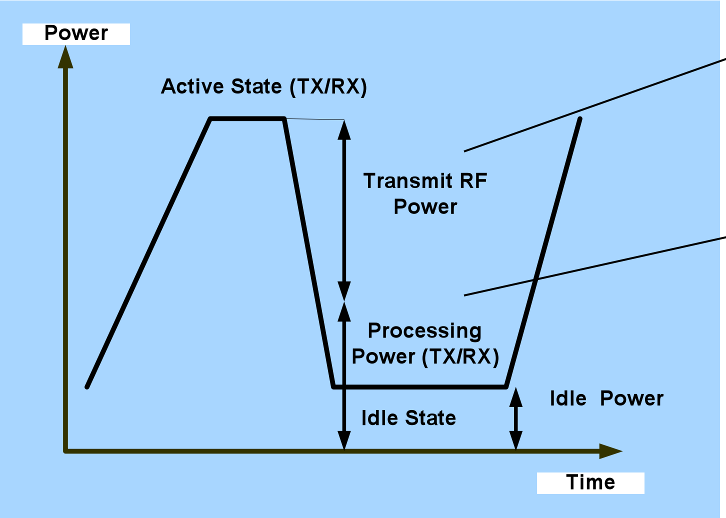
Total energy consumed by all BS/load/coverage area

(Joules/bit/sq. meters)

Relative Metrics: Absolute Energy Efficiency

Relative comparison with $E_{b,\min}$ **(dB)**

**source: U. of Essex*



Power required for reliable reception of information

Power consumed in transmit/receive electronics

$$E_{total} = \underbrace{P_{Active-RF}T_{Active}}_{} + \underbrace{P_{Processing}T_{Active} + P_{idle}T_{idle}}_{}$$

Energy required for reliable transmission of information

Energy overhead of transmitting information

Address challenges in measuring "implementation dependent" energy efficiency

Smart Grids/GRIDMAN

Selected utility MAN-based applications*

Not exhaustive –to illustrate a range of requirements taken from C80216gman-10/0007

- Advanced Metering Infrastructure (AMI)
- Distributed Energy Resources (DER) Integration
- SCADA and Distribution Automation (DA)
- Advanced DA ("Self-Healing Circuits")
- Wide-Area Situational Awareness (WASA)

* - The Greater Reliability in Disrupted Metropolitan Area Network (GRIDMAN) study group was formed in Nov 2009 to study synergies between the applications previously studied in the Network Robustness and Reliability (NRR) Ad Hoc and Smart Grid applications. They have developed a draft PAR which partially addresses the needs of the application above: IEEE 802.16-10/0013

Self-healing Networks

Preface

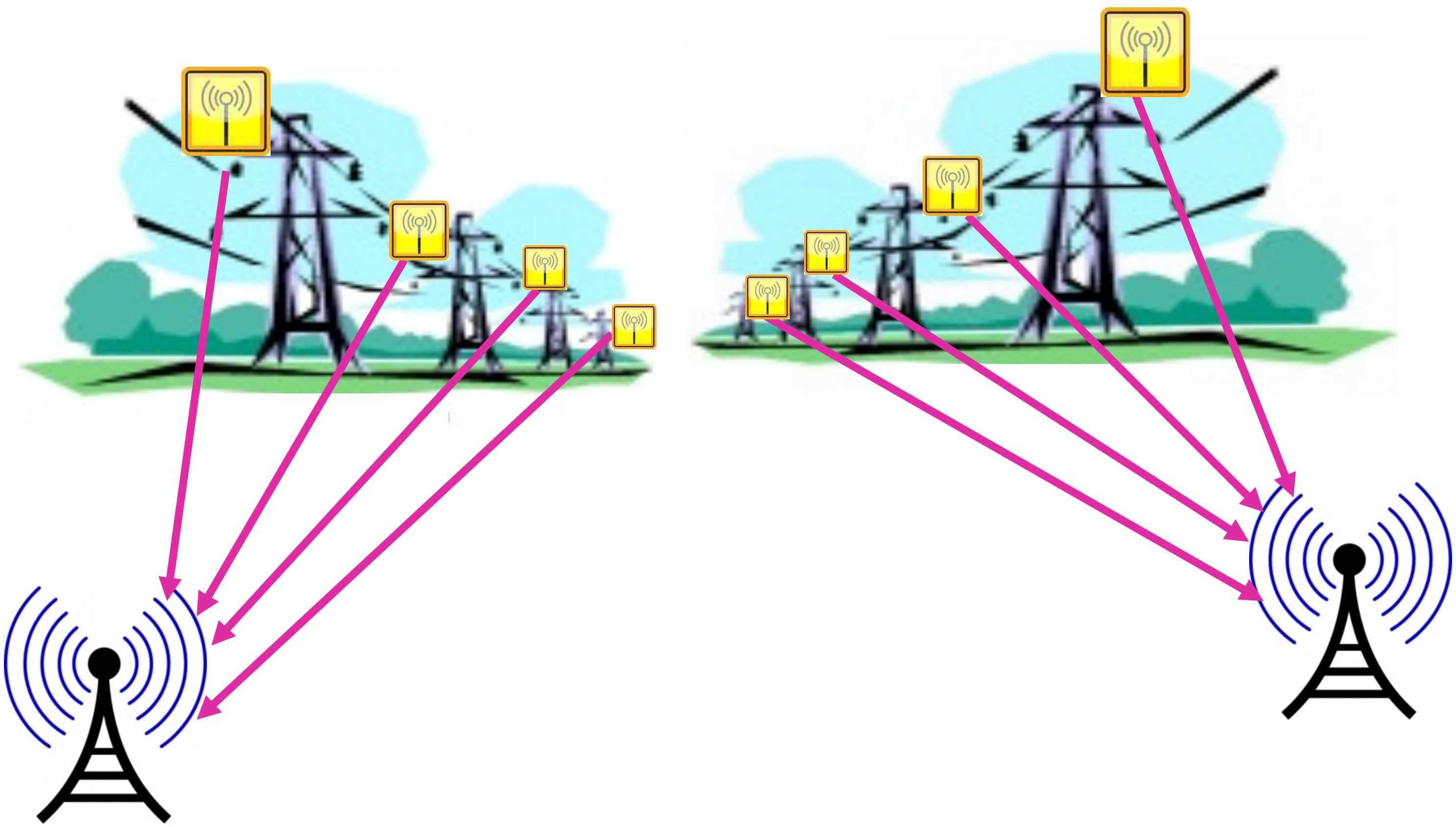
- “To have a self-healing network, you cannot rely on a single point of failure, as you would with WiMax or cellular technology”

http://www.greentechmedia.com/articles/read/smart-grid-networks-now-vs-the-future/

Disrupted WMANs

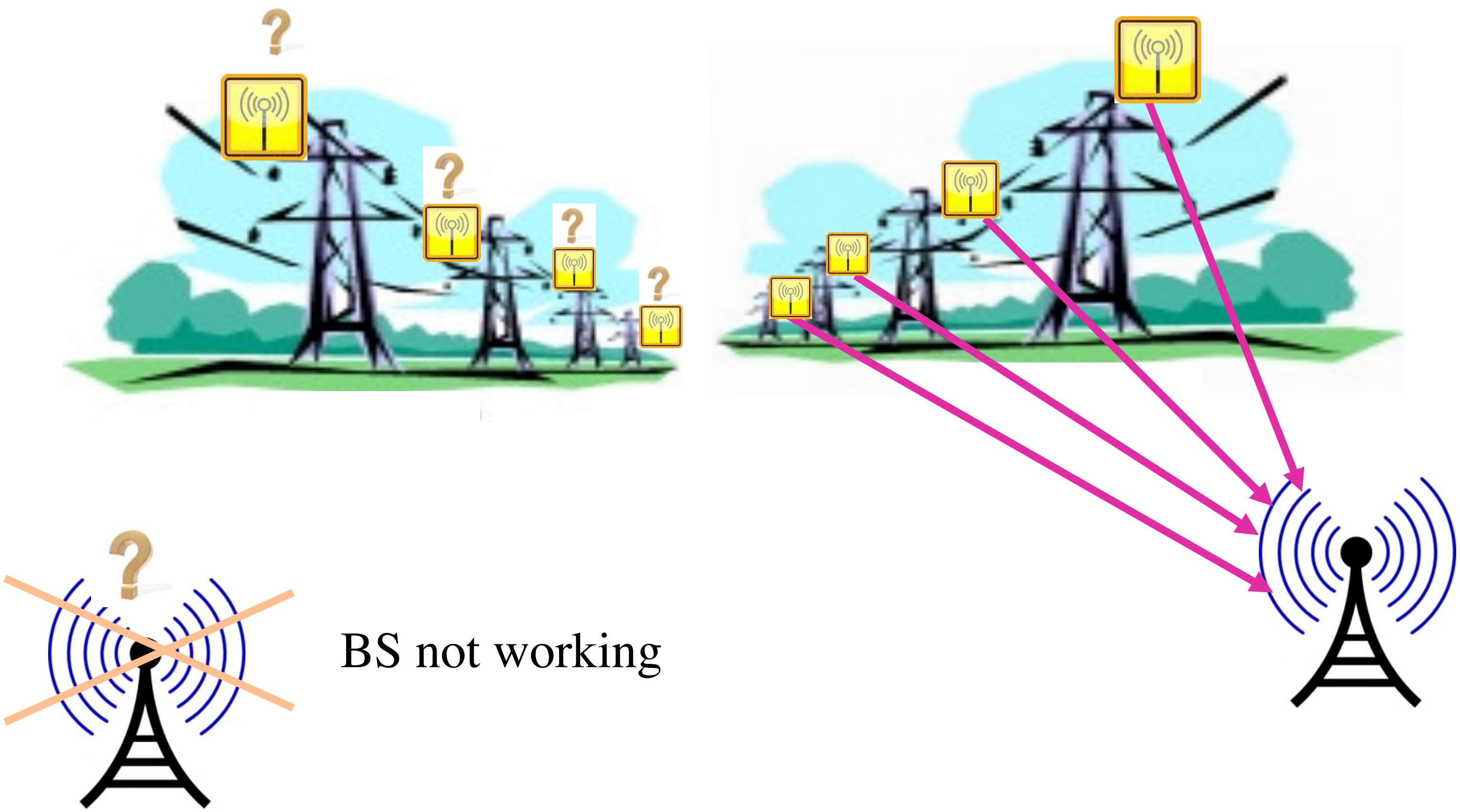
- Basic configuration:
  - P-MP, eventually including Relays
- Disruption
  - BS failure
  - Relay failure
- Self-healing
  - Find alternative ways for connection to the backbone

Scenario 1: Fixed Networks



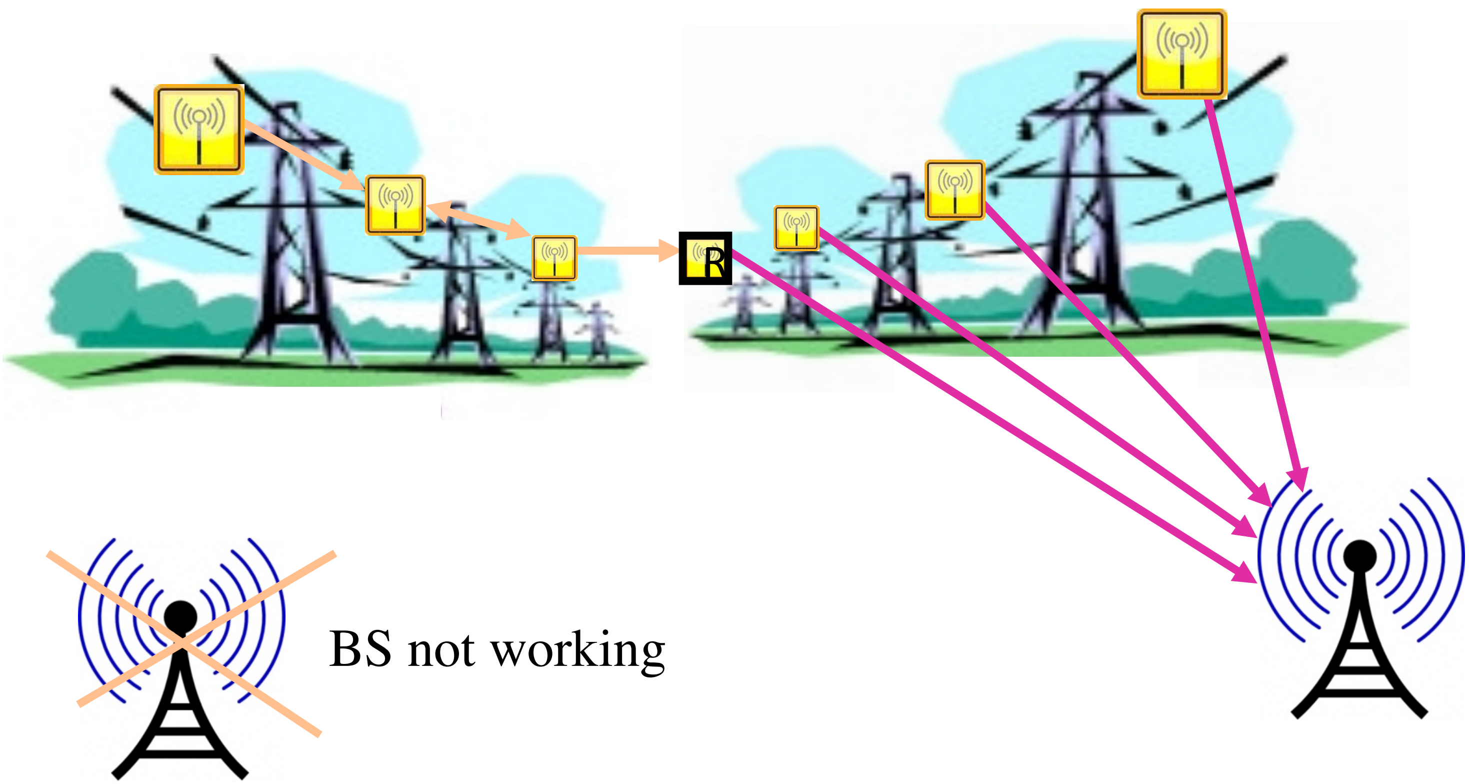
Disturbed network

SS lose connection with the BS



Self-healed network

SSs relay information

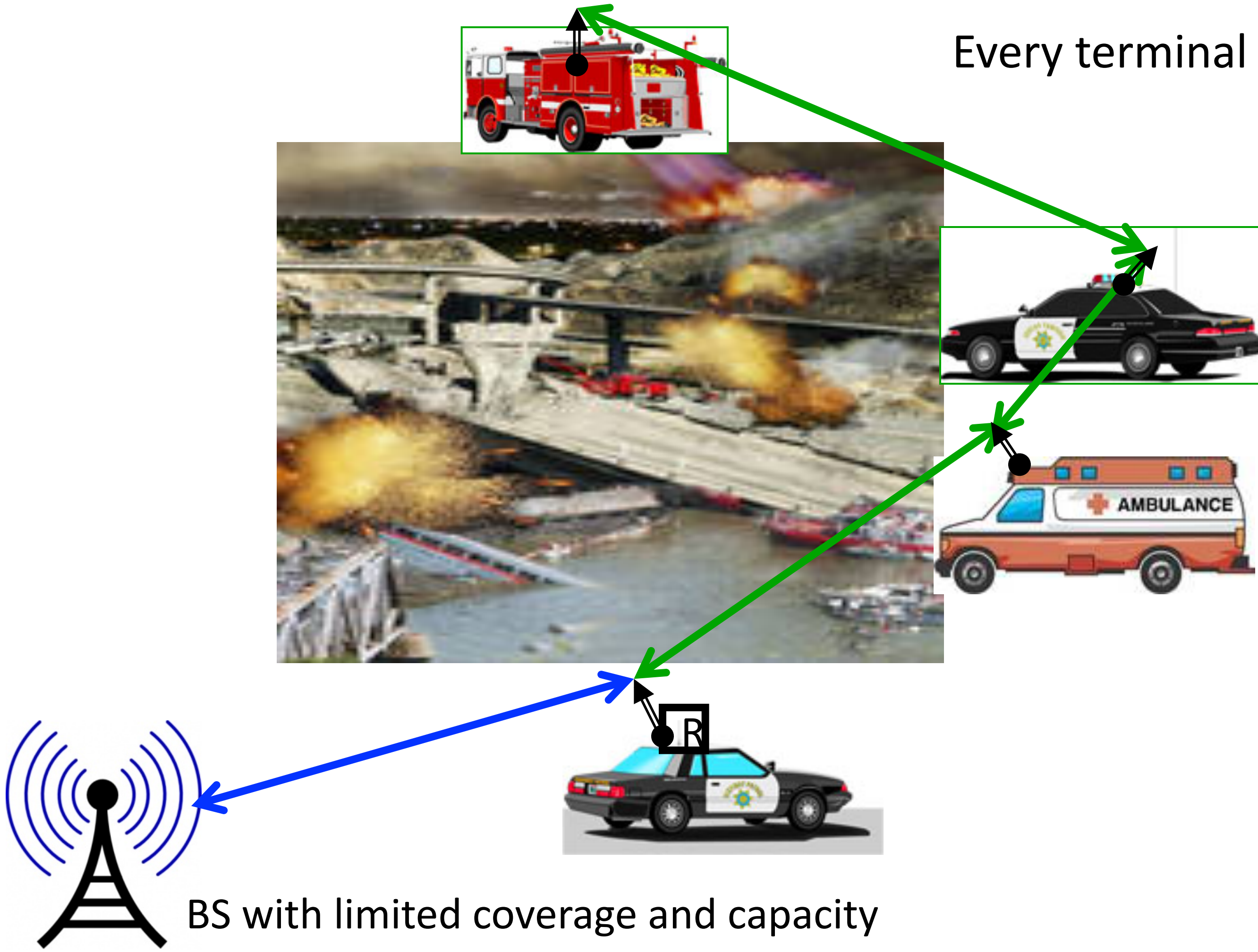


Healing solutions and topics

- SS to SS communication
  - Multi-hop relaying function included
    - PHY changes to SS
- Ability to connect through a neighbor network
  - May belong or not to the same operator
    - Access rights?
    - Security?
  - May use or not the same frequency
    - Hand-over between different frequency bands
    - Hand-over between licensed and un-licensed
  - May have or not enough available capacity
    - New traffic classes and real-time spread of the traffic across multiple frequency allocations

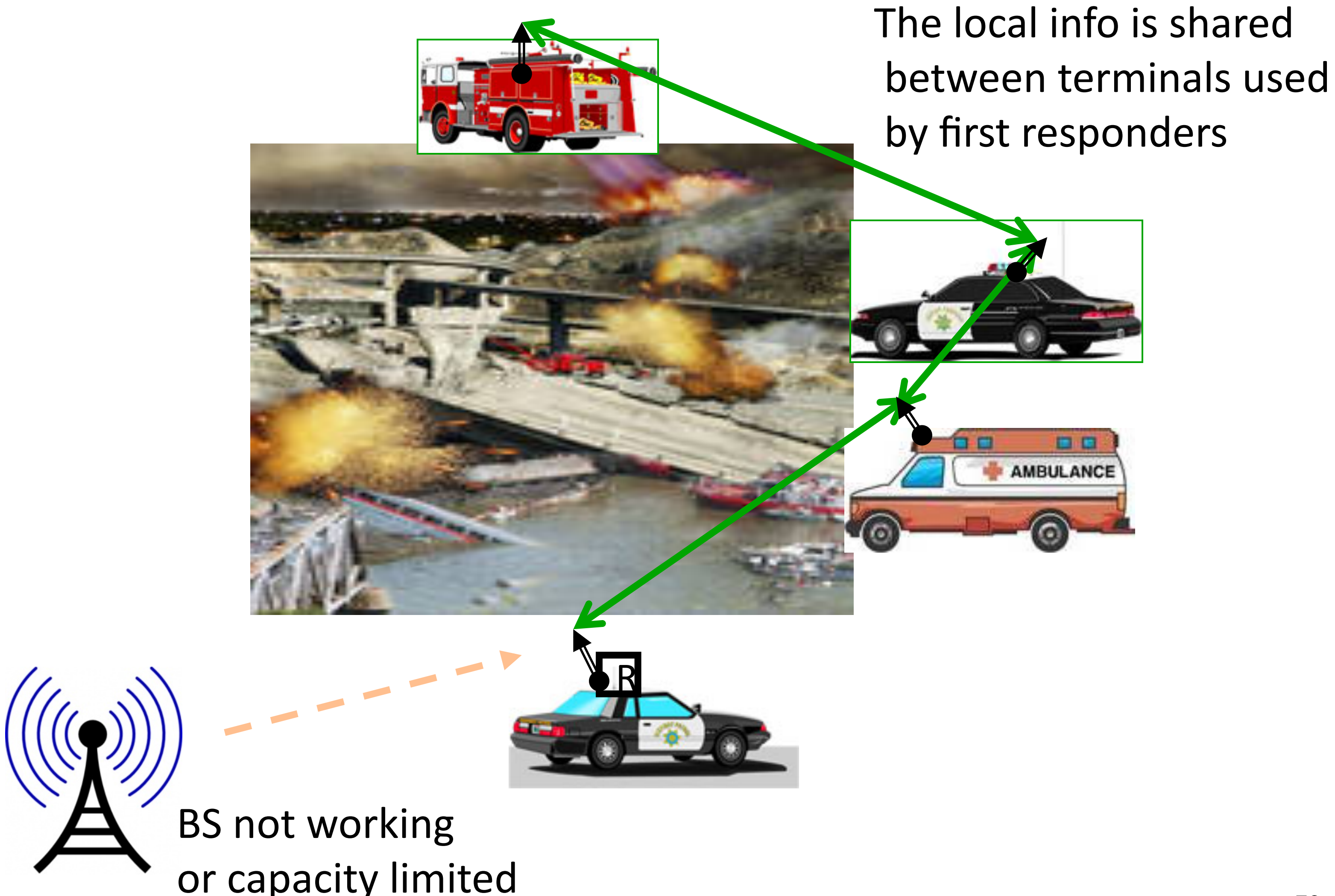
Scenario 2: Mobile Networks in disaster location

Every terminal relays info



BS with limited coverage and capacity

Scenario 2 – realistic situations



Topics

- MS to MS communication
  - Multi-hop relaying function included
    - PHY changes to SS
- Ability to connect through a neighbor network
  - First responders: different entities involved (police, fire brigade, health, etc.)
    - Access rights?
    - Security?
- Spectrum
  - May have or not enough available capacity in licensed spectrum
    - New traffic classes and real-time spread of the traffic across multiple frequency allocations

Conclusion

- MS-2-MS or SS-2-SS direct communication is requested for smart grids and public safety applications
  - Specific issues should be addressed
    - PHY, MAC, Networking
    - Simultaneous usage of multiple frequency bands