802.16 – A Worldwide Broadband Mobile Internet Standard

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Outline

- Broadband Services, Status and Markets
- Core Technology
- 802.16e Features and Differentiation
- Radio Network PHY
- Radio Network MAC
- Core Network
- Summary

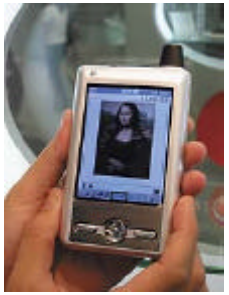
802.16e Services

Broadband Multimedia Information / Entertainment over IP

Fixed Mobile Convergence

Indoor terminal

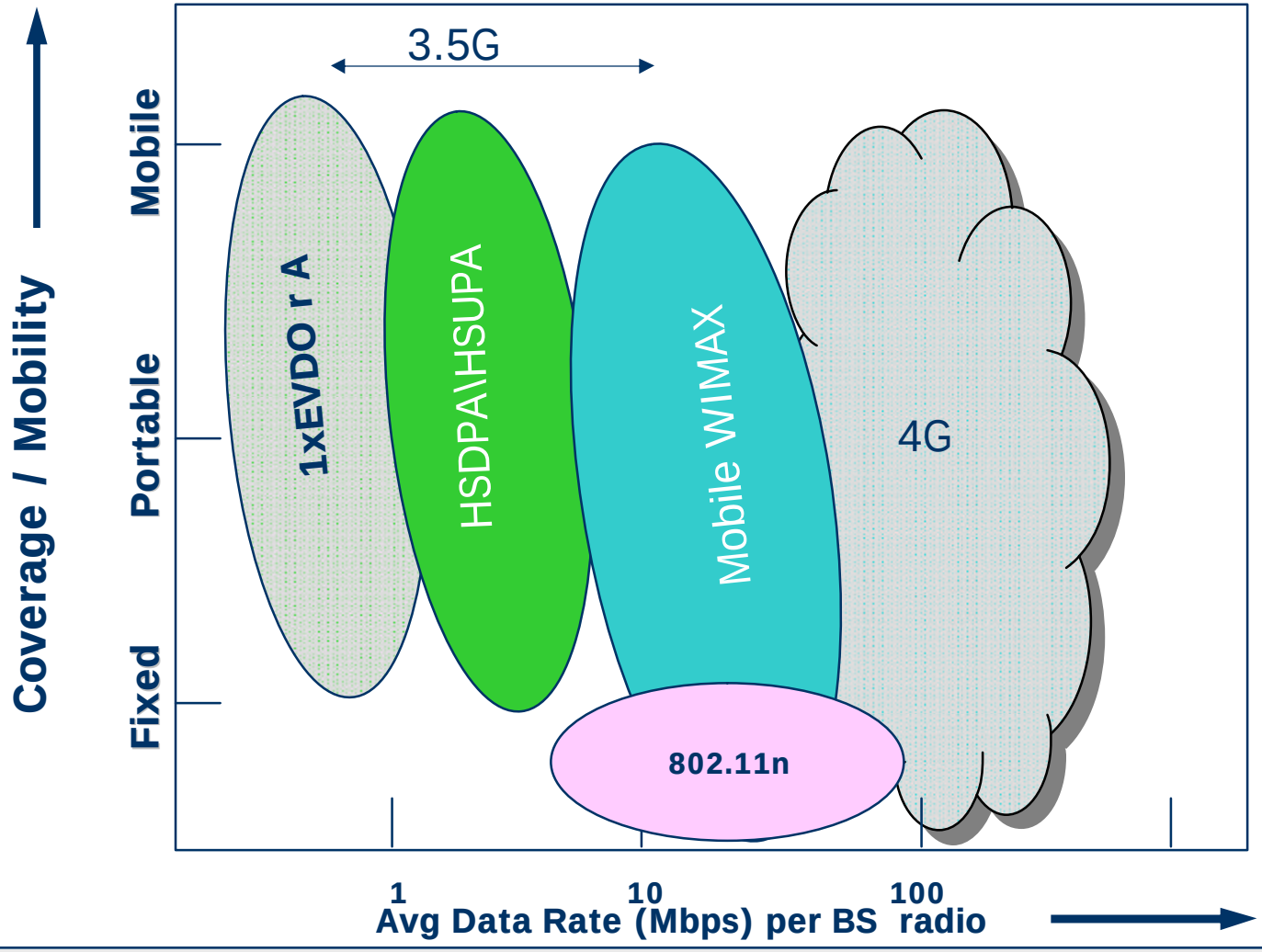
Portable terminal



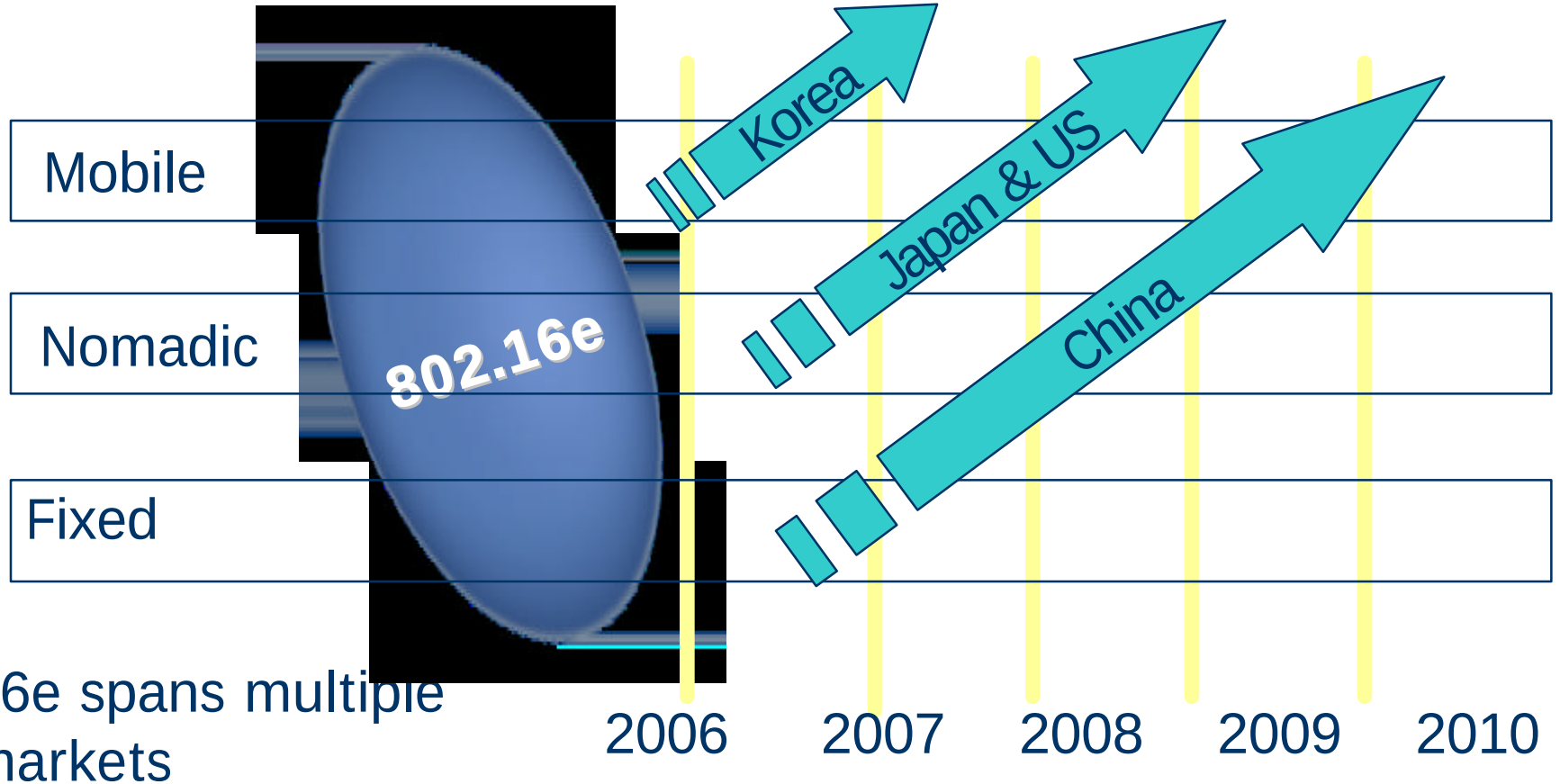
Mobile terminal

Consumer Devices

Wireless Internet Standards



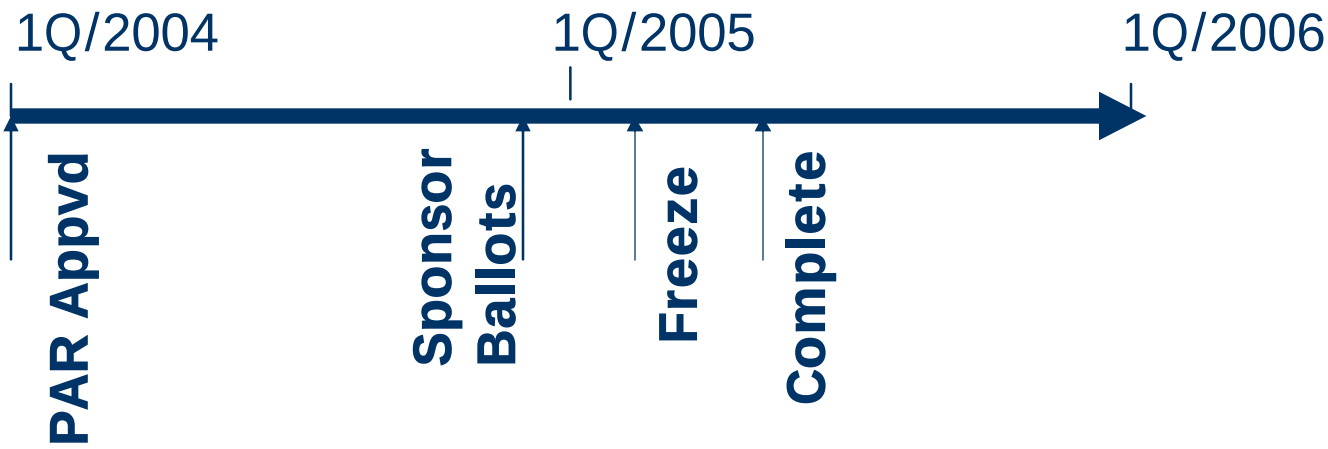
16e Market Start Dates



16e spans multiple markets

16e Standards Status

- Evolution of 802. 16d to support mobility
- 95% complete
- Adds new functionality – Scalable OFDMA, H-ARQ, MIMO, ..



16e is significantly more advanced than 802.16d

WIMAX

- Industry profile harmonization body
- WIMAX – 16d
  - Certification infrastructure set up, starting soon
- WIMAX – Mobile
  - MTG
  - NWG
  - Certification infrastructure being set up

3.5G Technologies

	DO Rel A	HSDPA	WiMax (802.16(e))
DL peak data rate Bandwidth	3.07 Mbps 1.25 MHz	14.4 Mbps 5 MHz	70 Mbps 20 MHz
UL peak data rate	1.8 Mbps	2 Mbps	20 Mbps
IP termination	RNC/PDSN	RNC/PDSN	BTS
Bandwidth efficiency features	- CDMA + Low latency - IP at RNC**	- CDMA + PHY HARQ - IP at RNC**	+ OFDM - MAC HARQ* + IP at BTS
Standards compatibility	Yes	Yes	Yes
Deployment	2005	2005	2005
Duplexing	FDD	FDD	TDD / FDD
BB complexity (incl. memory)	~1.2 million gates	~ 1 million gates	~ 2.5 million gates

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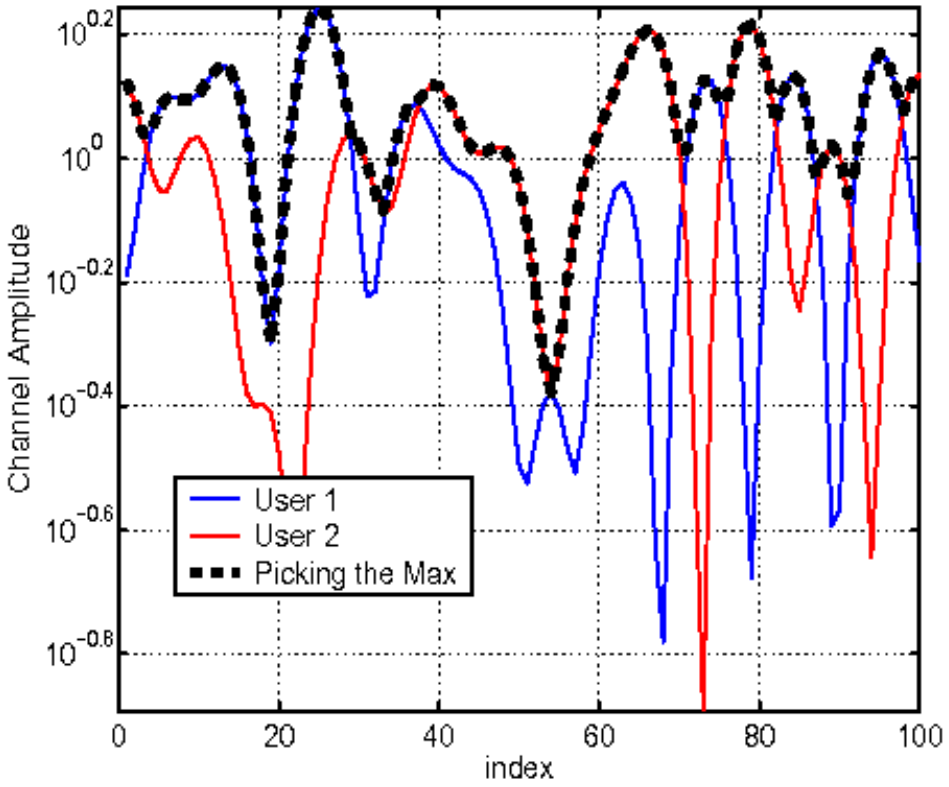
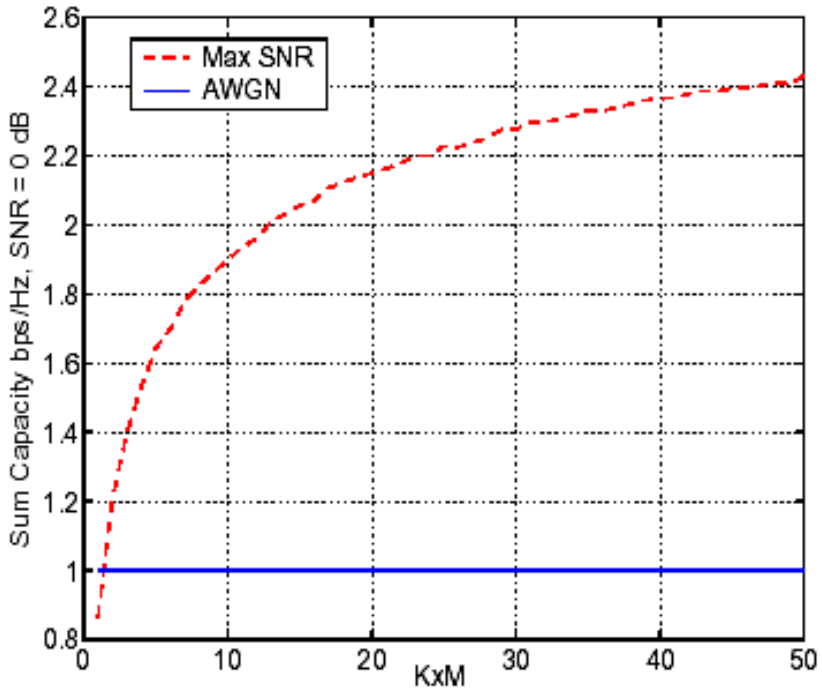
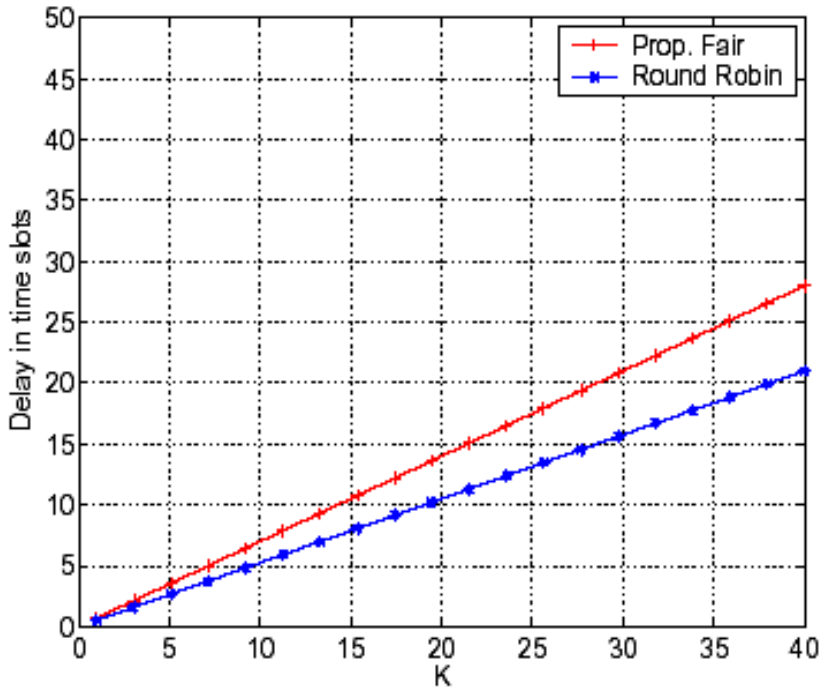
Opportunistic Scheduling (OS)



Scheduling users with maximum rate (channel gain), improves sum capacity

Capacity and Delay in OS

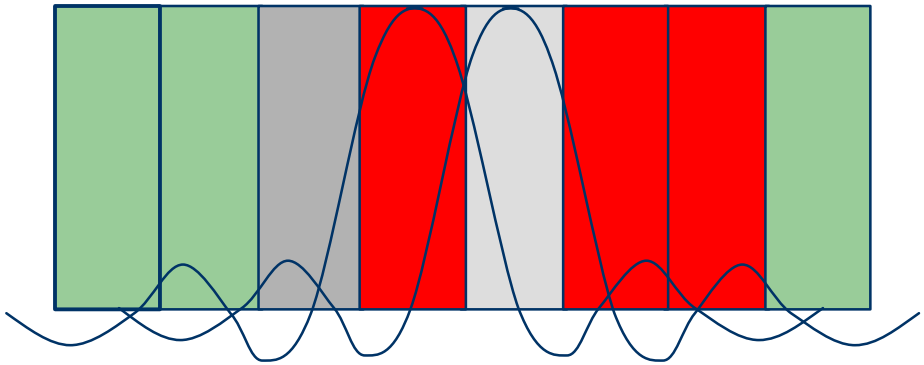




C ~ *O* (log log K) K users

Delay ~ *O* (K log K) for Prop. Fair Scheduling

OFDMA



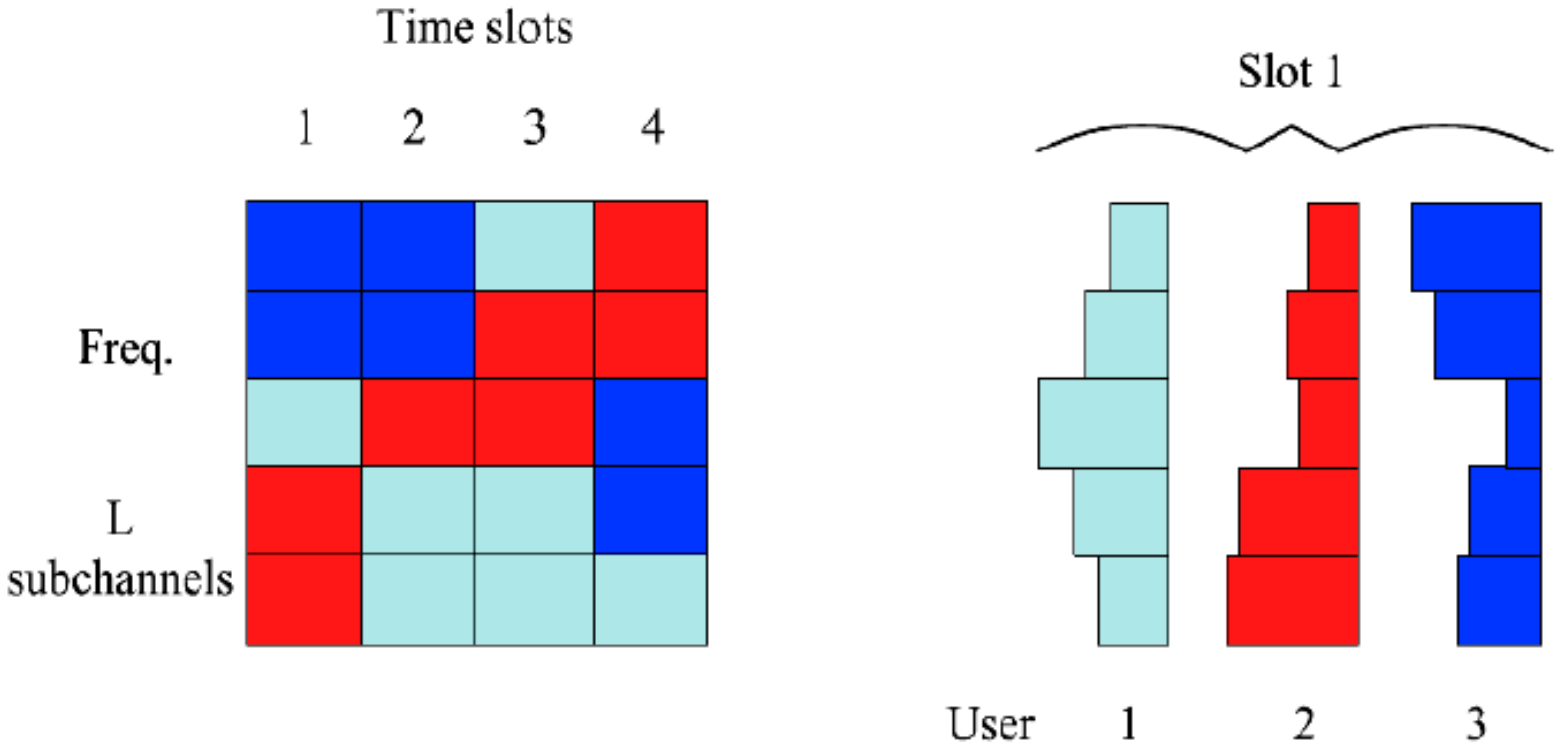
- Users allocated to sub channels
- No multi-path and multi-user interference
- Permits frequency specific user power, bandwidth allocation, pre-coding, beam forming,...

OFDMA vs CDMA Single Sector

	OFDMA	CDMA
Multi-path Interference	Avoids*	Needs equalization, noise enhancing
Frequency selective waterfilling	Yes	No
Freq. selective beamforming / pre-coding	Yes	Difficult
Multi-user interference on DL	Avoids*	Needs equalizer

*OFDMA advantage 20% or bigger in wideband
Multi-path rich urban channels. OFDMA advantage stronger at high SNRs

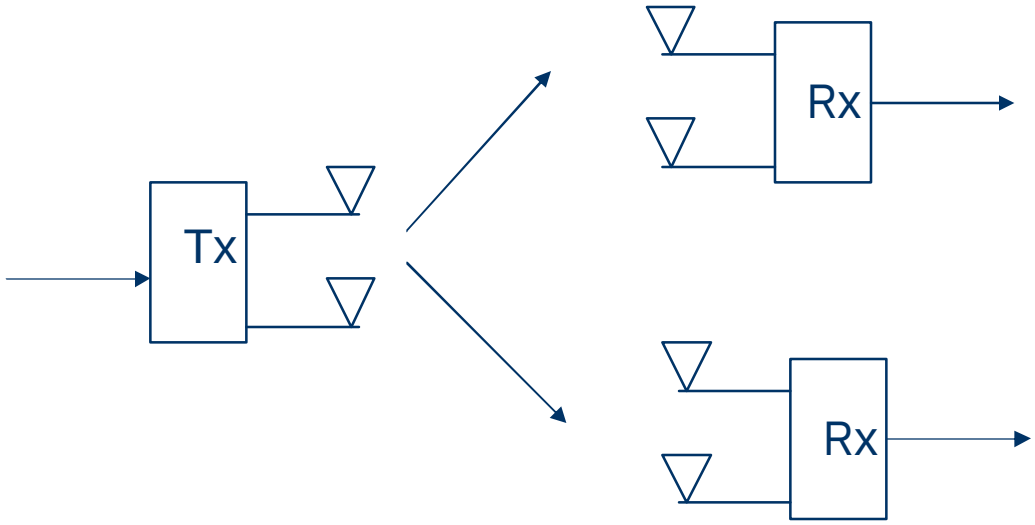
Opportunistic OFDMA



Every subchannel is scheduled based on max C/I

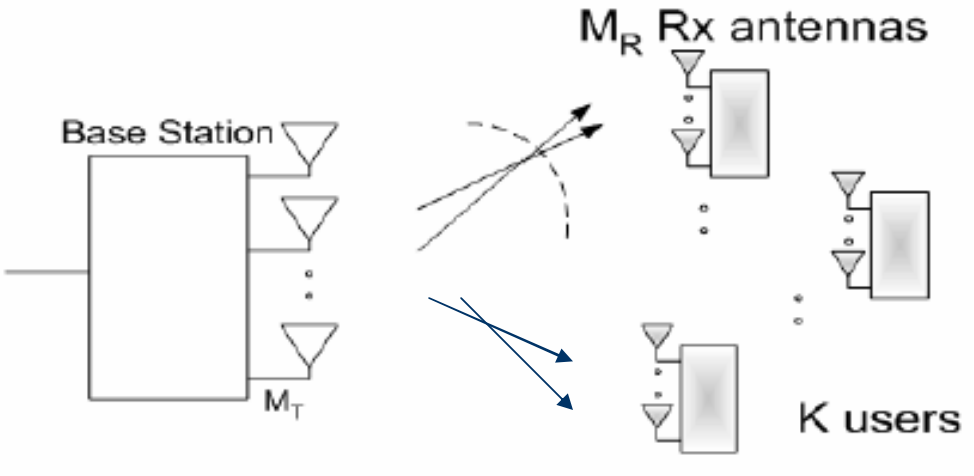
C ~ *O* (log log K)

MIMO



Use spatially diverse channels to support increased sum rates

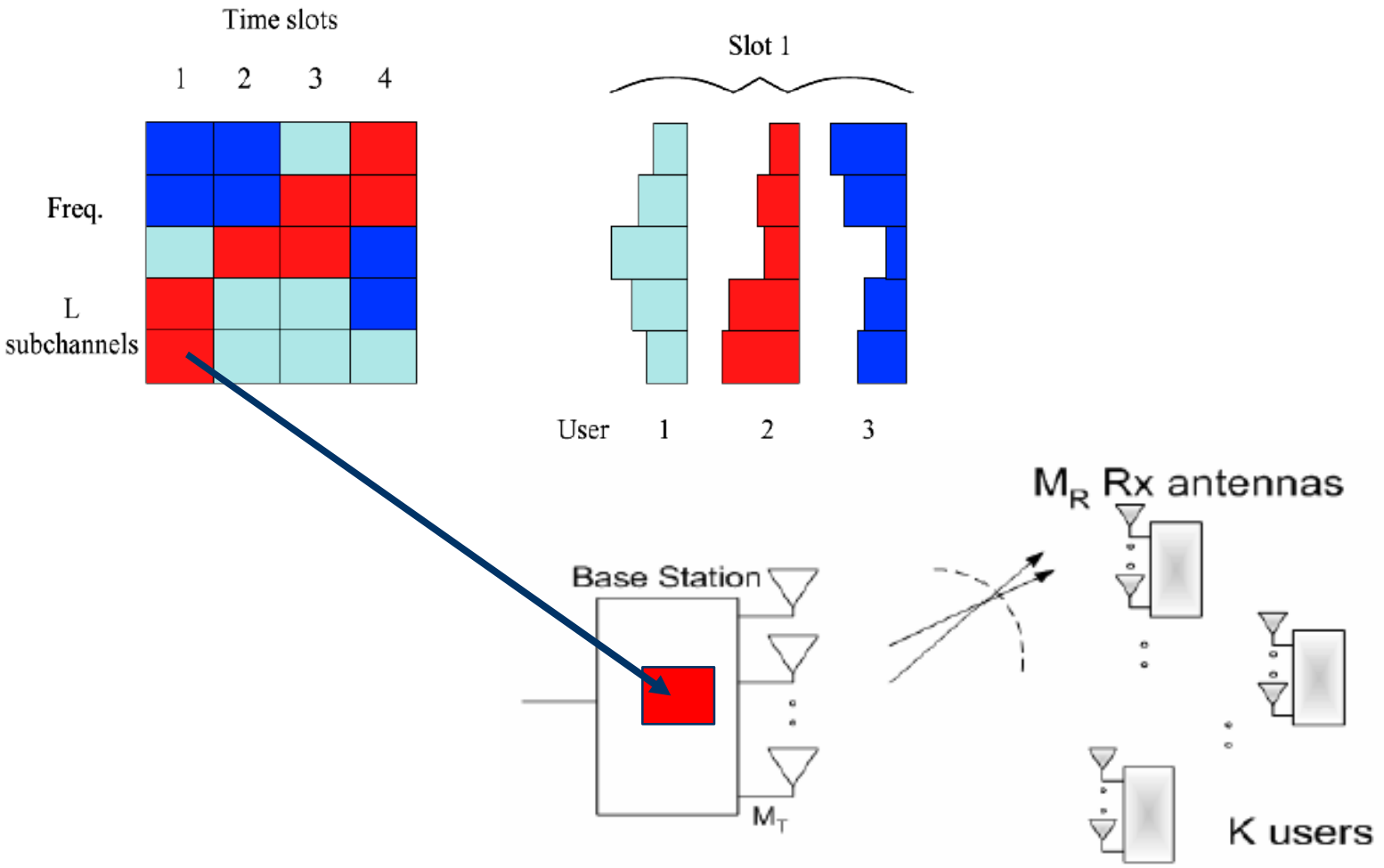
Opportunistic MIMO



Choose users who such that orthogonal Tx modes couple to the best available modes to maximize sum capacity.

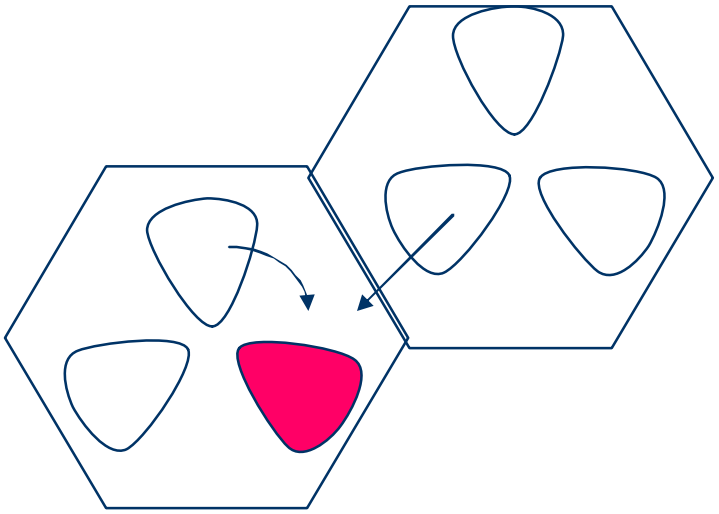
Users use linear processing only which is optimal

Opportunistic OFMDA+MIMO



Interference Sources – Per OFDMA MIMO Tile

- Multiple sectors in cell use same tile (sector reuse - antenna pattern separation)
- Multiple cells use same tile (cell reuse - cell-to-cell geographic separation)



OFDMA vs CDMA Multi-Sector

	OFDMA	CDMA
Multi-sector/cell interference	Variable reuse Interference avoidance Interference cancellation Variable spreading Interference averaging	Variable spreading, Interference cancellation Interference averaging

Both OFDMA and CDMA have interference variability issues

Interference Management, Cont'd

- Interference avoidance (variable reuse)
  - Drop reuse for selected tiles
- Power control
  - Power control across sectors / cells to increase sum capacity
- Variable spreading, interference averaging and link adaptation

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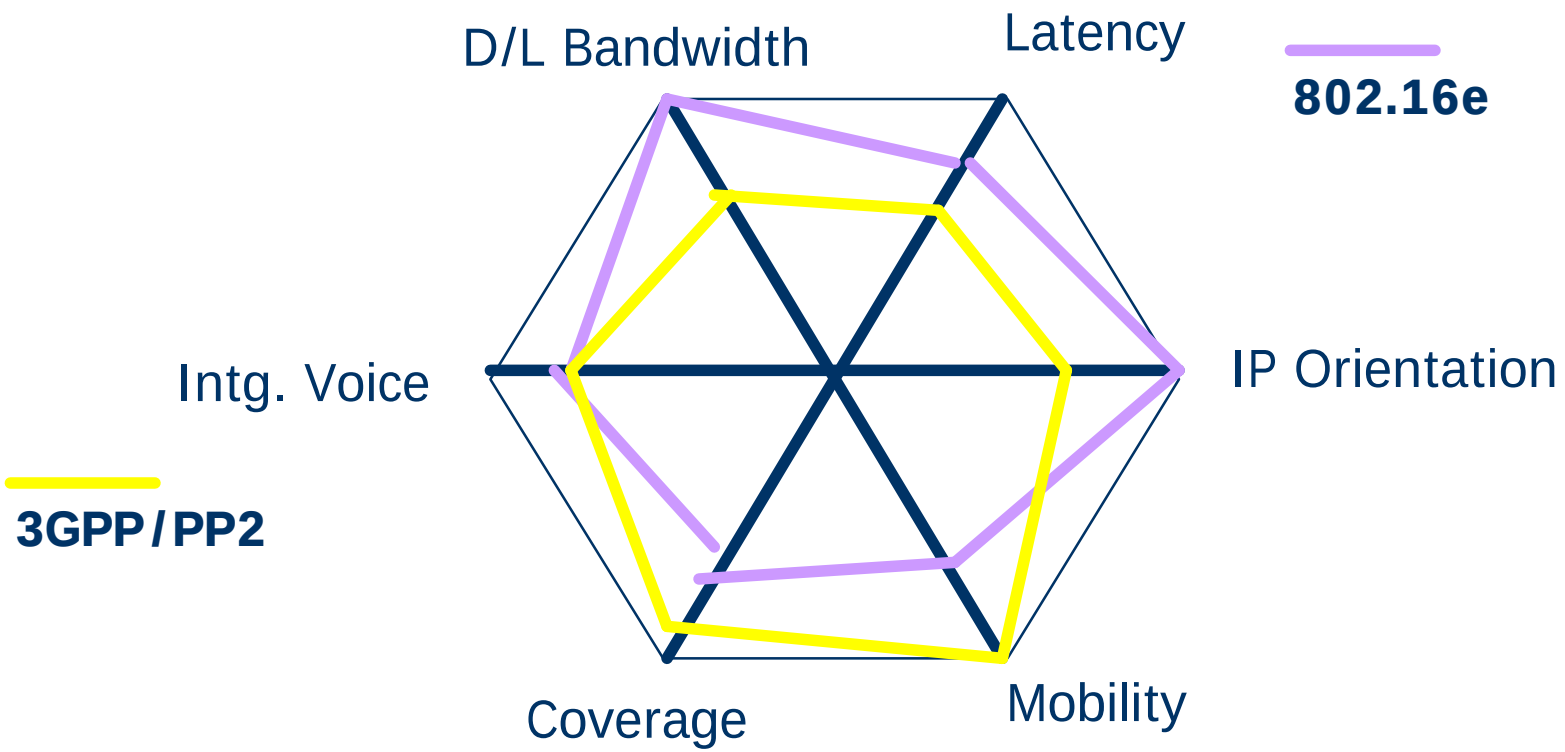
16e Key Features-1

- Flexible configuration to suit regional needs
  - Channelization 10, 5, 3.5,.. MHz
  - Band plans 2.3-2.4, 2.5-2.7, 3.4-3.5 GHz
  - Fixed Mobile Convergence
- Broadband services delivered over IP
- Mobility support (capacity degrades gracefully > 60 Kmph)
- All IP core network architecture
- Single frequency network deployment

16e Features - 2

- Future proof
  - Support any applications running over IP
  - Advanced PHY and MAC with 4G features
- Low power / high energy efficiency
- Low cost - $ / Mbps / Sq. Km
  - Standards based, wider pipes, low IPR overhead, end-to-end IP, simpler to develop, deploy and manage.

Design Tradeoffs Comparison



16e Offers Multi-Service Capability

- Fixed Mobile Convergence - Single RN and similar CN infrastructure
- Can upgrade from fixed to mobility without forklift
- 16e outperforms 16d in fixed / portable applications
- Performance in fixed / portable about 2X of mobile
- Better value chain and volume benefits customers and service providers

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PHY Features

- OFDMA with variable power, spreading and reuse
- Fine grain modulation and channel coding
- Space time Coding
- Pre-coding
- Fast link adaptation
- Hybrid ARQ
- Advanced interference management

OFDMA Advantage

- Avoids multi-path and intra-sector interference
- Sub-channelization balances link on U/L for low power terminals
- Higher spectral efficiency compared to CDMA for broadband packet access
- Access to frequency dimension offers greater flexibility in using resources
- Cleaner and simpler incorporation of MIMO

OFDMA offers 1.5 X performance over CDMA

Inter Cell Interference Mgt.

- Variable power (Power Control)
- Variable spreading via repetition coding
- Variable frequency reuse - 1x1 and 1x3 hard reuse zoning and soft (opportunistic) reuse
- Interference averaging in certain modes
- Multi-antenna can provide interference rejection

Multiple Antenna Support

- Improves capacity and coverage through
  - Space diversity, Beam forming, Spatial multiplexing and Interference cancellation
- Unified multi antenna mode captures all these leverages via
  - MIMO Zone with ST coding and Pre-coding to exploit channel state information at Tx

Multiple Antennas Offer x2 to x3 performance over SISO Systems

TDD and FDD

Item	FDD	TDD
Frequency Availability	Good	Fair
DL/UL Asymmetry	Difficult	Easy
Hardware simplicity	Fair	Good
BS Synchronization	Optional	Essential

Both modes supported. TDD has 1.20 X advantage for broadband asymmetric services

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MAC Features

- Full wireless QoS
- Uses header compression (ROHC, IPHC), addressing, fragmentation and packing to increase efficiency
- Packet sizes adapted to trade throughput and latency
- Scheduling in frequency-time is SNR, channel and QoS aware
- Unicast, and IP multicast / broadcast groups supported

Scheduler

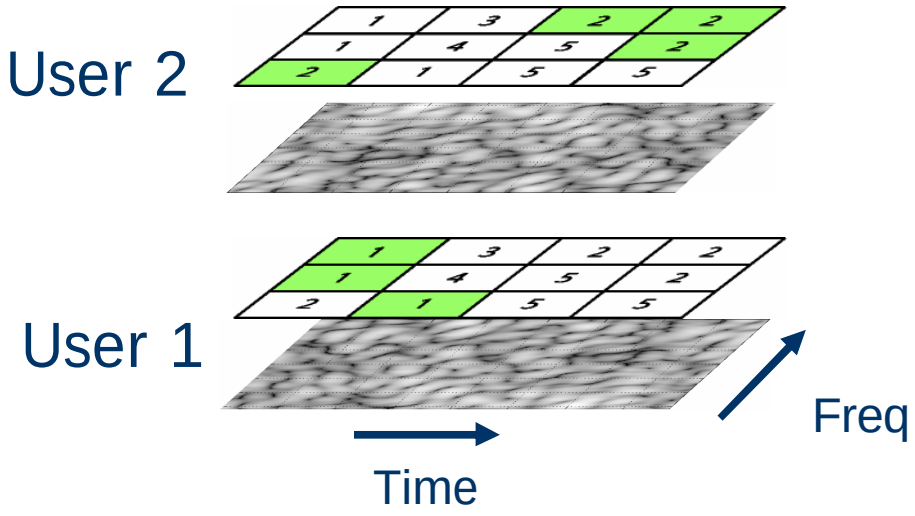
- IP QoS aware
- Down link - Incoming traffic is classified based on IP QoS (Int Serv/ RSVP, Diff Serv AF, EF, BE) and then allocated bandwidth.
- Up link - Bandwidth is allocated for UGS, or via requests from polling or light weight contention channel requests
- D/L and U/L MAPs broadcast on burst profiles

QoS

Scheduling Class	Application	Delay Sensitivity	QoS Class
UGS	Voice	No delay	TDM voice
Real time Polled Srv (rtPS)	VOIP, Streaming Video	High	Streaming VBR
Non Real time Polled Srv (nrtPS)	Web browse, messg, games	Moderate	Interactive TFTP HTTP
Best Effort BE	Email FTP	Low	Background

Multi-User Diversity Scheduling

- Maps users to tiles (Freq.-time) with most favorable channel
- Outperforms similar approaches in CDMA
- Performance gain about 2X with 25 users in the pool



Radio Link Protocol

- Efficient ARQ or H-ARQ with chase combining and incremental redundancy
- Fast ACK/NACK channel.
- Power boost to force H-ARQ packet termination
- Low round trip times, avoids TCP time outs and supports interactive data
- ARQ resets in handoffs (packet losses)

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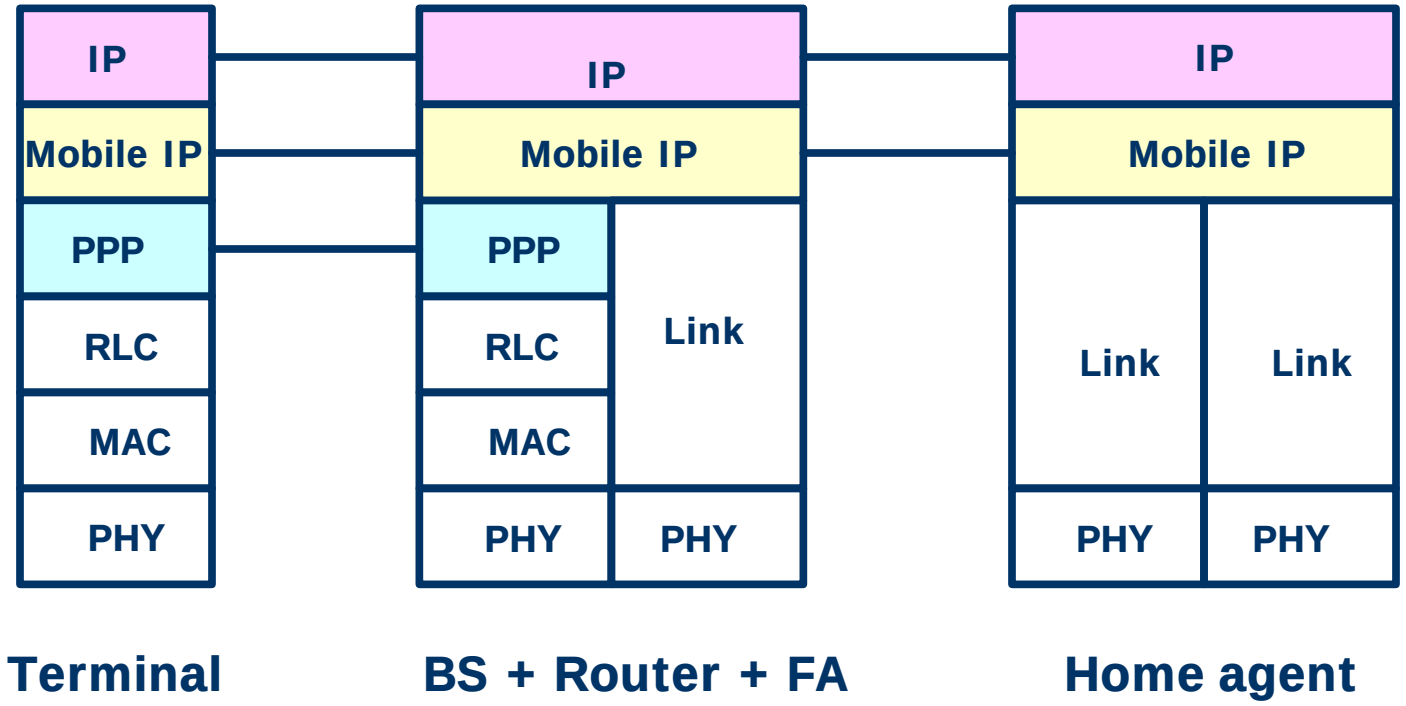
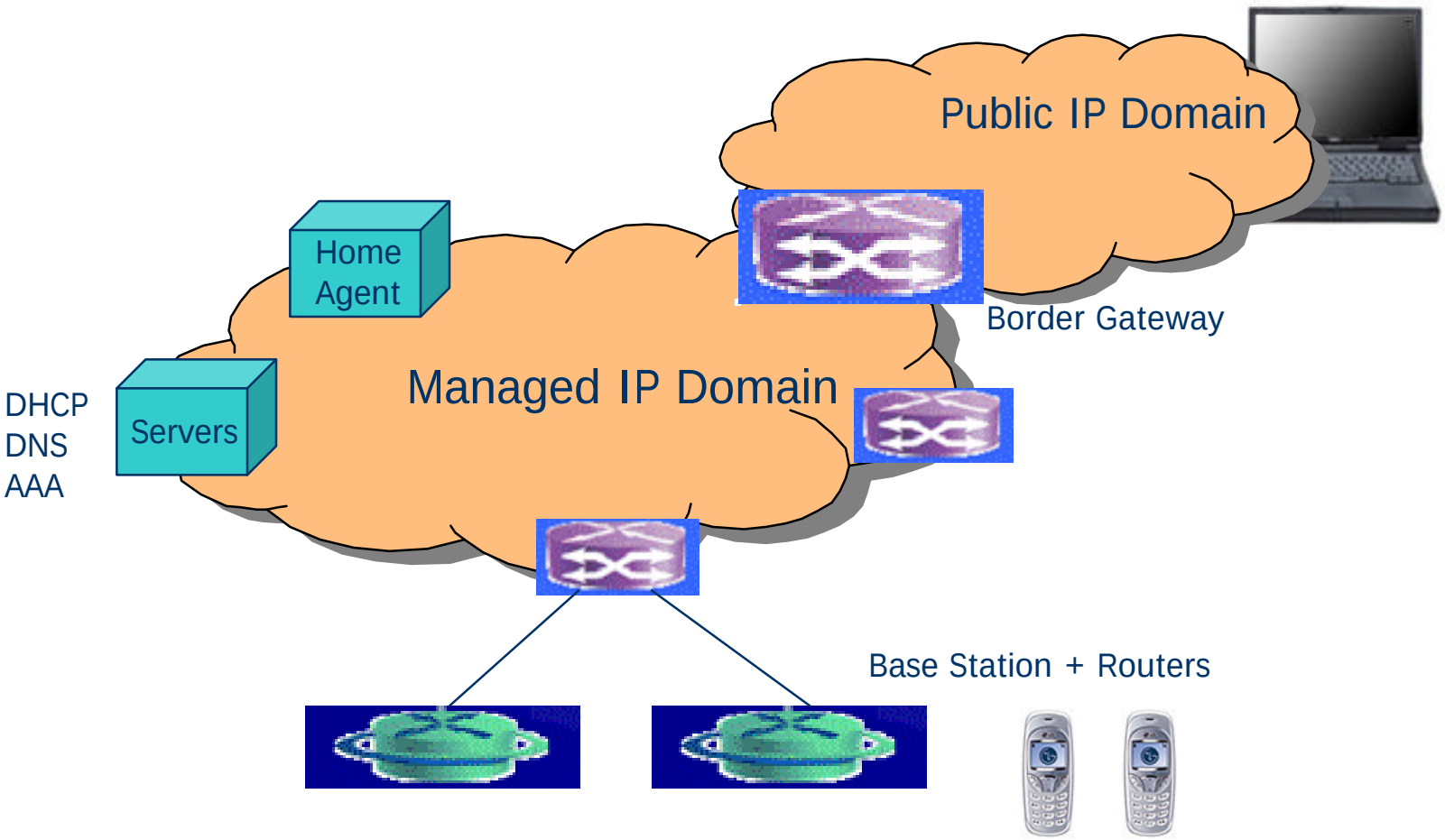
Nominal Protocol Stack



CN Architecture

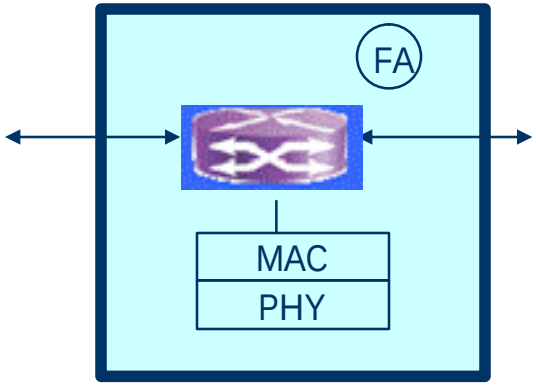
- All IP core
- Mobile router integrated into BS and eliminates number of boxes (SGSN / PDSN, RNC,..) and flattens the network
- Easier scalability as intelligence is pushed to the edge (BS)
- Handoff supported through mobile IP with Home Agent, Foreign Agent and handoff extensions
- External corresponding node shielded from mobility
- Efficient IP multicast

IP Core Network

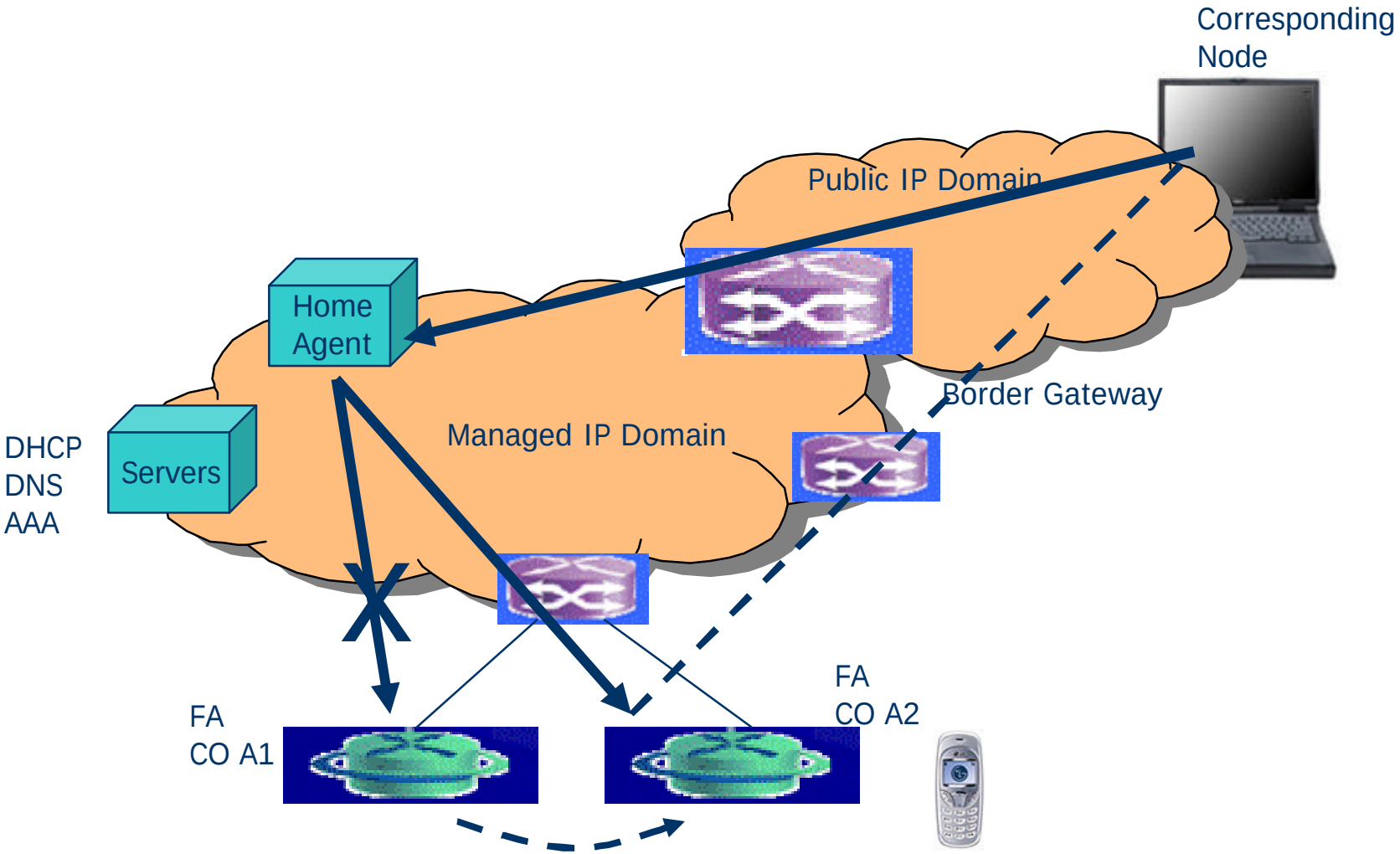


Router Integrated Base Station

- BS is IP aware and hence scheduler can enforce IP QoS
- Local processing improves response time (for scheduling, AMC, ARQ) and overall lower latency
- Tightly coupled RLC, ARQ and scheduling for cross layer functions and QoS performance on handoffs



Mobile IP Handoff



Handoff

- Minimum packet loss and latency
- Layer 2 handoff
  - HA uses vanilla Mobile IP
  - FA uses Mobile IP + Handoff extensions
- Layer 1 handoff
  - Hard handoff likely to be finalized
  - Soft handoff more complex and will not enter current Rev

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Deployment Issues

- No frequency planning (SFN)
- Easier scalability / cell splitting
- Ideal frequency band around 1.8- 2.7 GHz, some reduction in performance above 3.0 GHz particularly for mobility
- Co-located on current cellular towers with another tier of antennas
- CN can use same managed IP domain supporting current cellular network

16e Network will be Cheaper

- International standard with early volume ramp ups in Korea, ..
- Broader pipes – lesser BS to deploy
- Simpler system to develop (OFDMA), less internally coupled than CDMA. Less optimized also.
- Simpler network to fine tune in deployment (OFDMA)
- Much lower intellectual property overhang
- All IP delivery and simpler IP core network

Summary

- 802.16e offers lowest cost option for broadband wireless
- First trials in 4Q/05
- Multi-service network can be evolved from fixed to mobile seamlessly
- Future proof technology with many 4G features

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