Mobile Broadband Internet Access
What Comes Next?

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Work supported by German Ministry of Research & Education and EU-IST WINNER project

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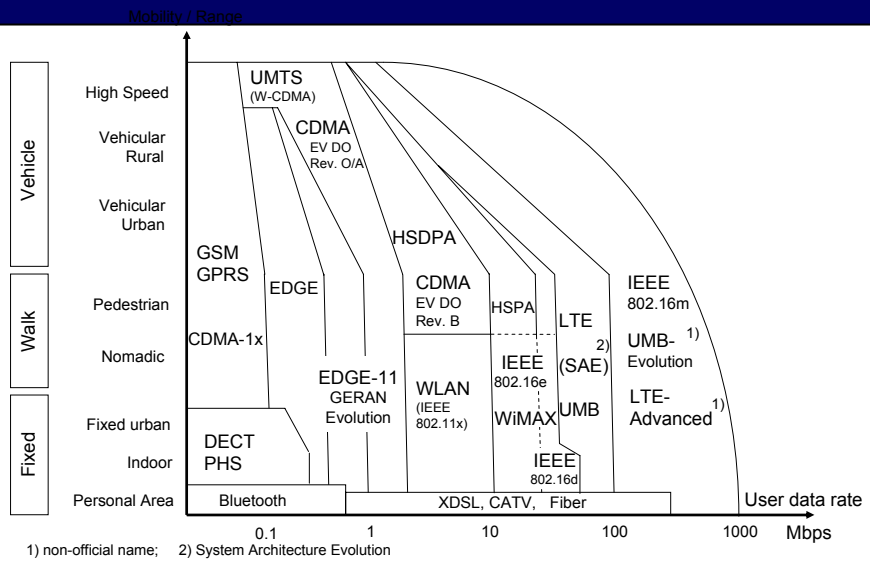
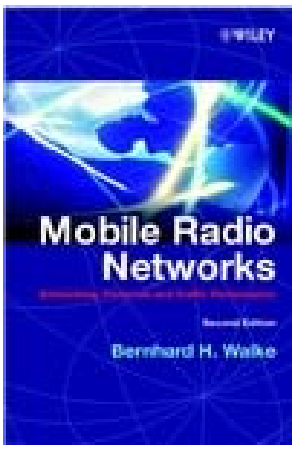
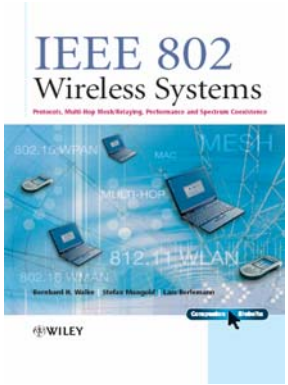


Source: Takagi/Walke: Spectrum Requirements Planning in Wireless Communications, J. Wiley 2008

Recent Books by ComNets



March 2002



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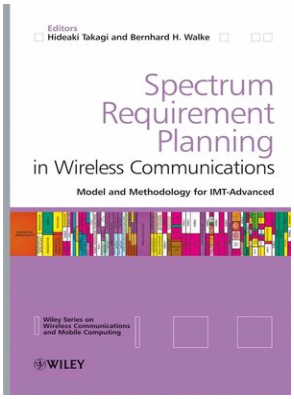
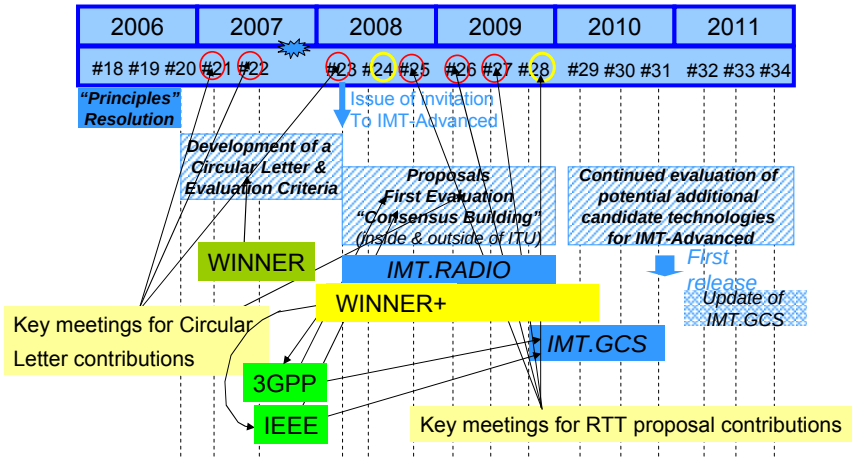


April 2008

Standardization of IMT-Advanced Systems

IMT-Advanced process of ITU-R



- Tight ITU-R time plan in conjunction with time schedule of regional and global standardisation bodies
- Strong global competition expected

GCS: Guidelines & Criteria Specs

Source: ITU-R

WINNER = Wireless World Initiative New Radio

Circular Letter "On an Invitation to Propose Candidate Radio Interface Technologies for IMT-Advanced"

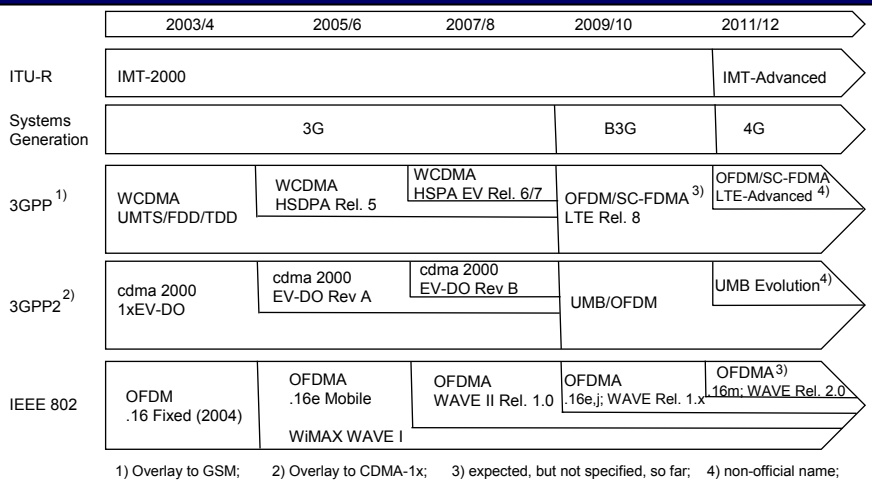
CL has a short main body and 9 Annexes:

- Annex 1: Background on IMT-Advanced
- Annex 2: Submission & Evaluation Process and Consensus Building
- Annex 3: **Requirements related to service capabilities**
- Annex 4: **Requirements related to technical system performance** of IMT-Advanced radio interfaces
- Annex 5: **Spectrum related issues including relevant requirements** (e.g. spectrum utilization related)
- Annex 6: Submission guidelines & template for details of submission
- Annex 7: **Evaluation guidelines and criteria and methodology**
- Annex 8: Relevant ITU-R Recommendations, Reports and others
- Annex 9: IPR policy

WINNER+ Contributions to IMT–Advanced

Contributions needed in the following areas:

- Technical minimum capabilities for the candidate technologies with respect to services, technology, spectrum.
  (relevant ITU-R Deliverables: *IMT.TECH* and Annexes 3,4,5,6 of *Circular Letter*)
- Evaluation guidelines and criteria (relevant ITU-R Deliverables: *IMT.EVAL and* Annex 7 of *Circular Letter*)
- Evaluation of IMT-Advanced candidate technologies
- Key characteristics for IMT-Advanced (relevant ITU-R Deliverable: *IMT.RADIO*)



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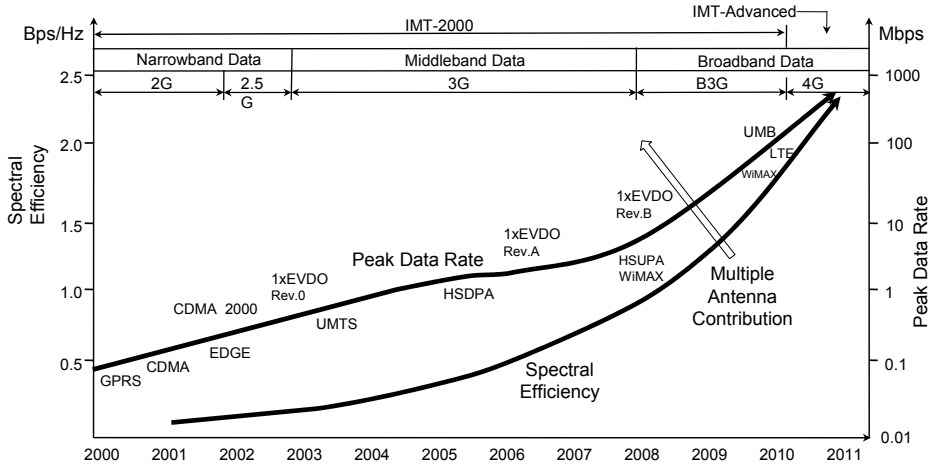


Source: Takagi/Walke: Spectrum Requirements Planning in Wireless Communications, J. Wiley 2008

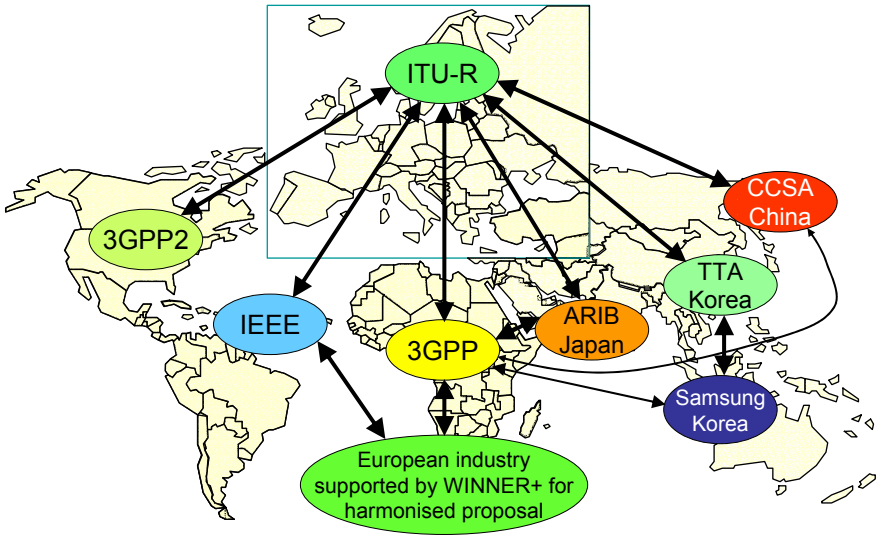
Means to Increase Throughput

- Higher 4G Systems Bandwidth (>40 MHz)
  - Available only at high carrier frequencies (>=3 or 5 GHz) ➔ Reduced coverage
    - Coverage extension with relays
- Higher Modulation Degree (more Bits/Symbol need higher SINR)
  - Interference Avoidance
    - Space Division Multiple Access (SDMA): Beam forming antennas
    - Orthogonal Frequency Division Multiple Access (OFDMA): Frequency Adaptive Scheduling
  - Atenna gain
    - Sectorization
    - Multiple Input Multiple Output (MIMO): multiple antennas at terminal required
- Lower Overhead in Medium Access Control (MAC) Layer
  - Longer frames
- Better Channel Coding

IMT-Advanced Candidate Systems

- 3GPP-LTE II / +
- Ultra Mobile Broadband (UMB) USA/QUALCOMM
- SUPER 3G (Japan)
- 3G+ (Korea)
- TD-SCDMA Ev. (China)
- IEEE 802.16m (based on 802.16e, j) cellular broadband
- IEEE 802.11n (ad-hoc component for cellular)
- WINNER+ (Europe)

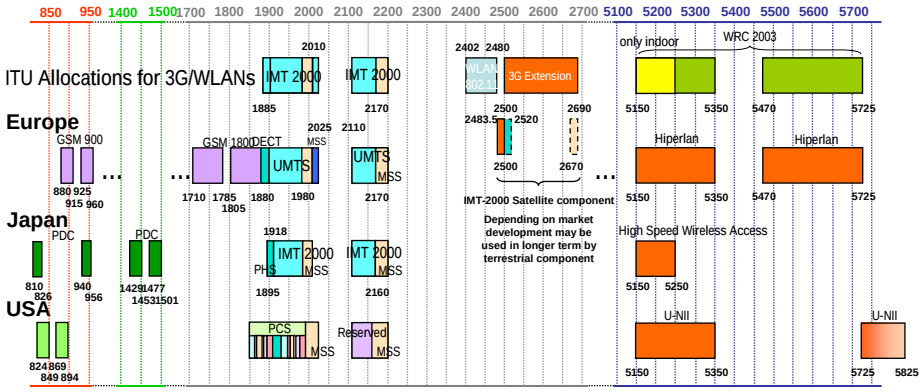
Expected international standardisation process



Source: WINNER+ proposal

Frequency Spectrum for IMT-Advanced

Frequency bands: 2nd / 3rd Generation & beyond

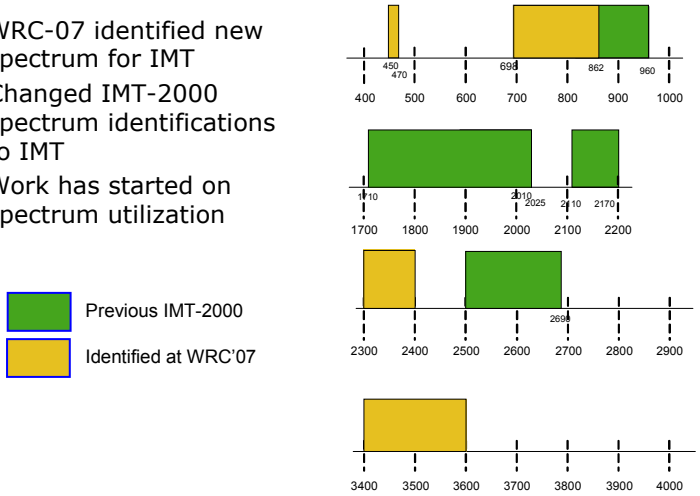


- WRC-07 will discuss and identify frequency spectrum for systems beyond 3G

Source: Siemens AG

Bands identified by WRC-07 for IMT Systems

- WRC-07 identified new spectrum for IMT
- Changed IMT-2000 spectrum identifications to IMT
- Work has started on spectrum utilization



Previous IMT-2000

Identified at WRC'07

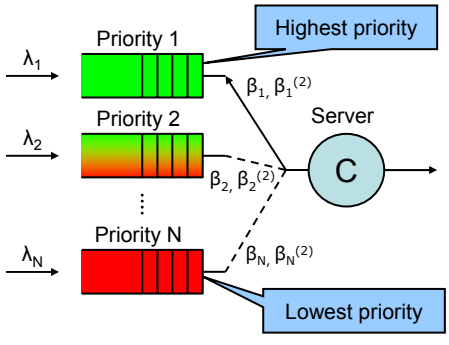
Simplified diagram!

How to Calculate the Required Spectrum for IMT-Advanced

- Circuit Switched Service: Multi-dimensional Erlang Model
- IP Packet Switched Service: Priority Queue (Cobham Model)

IP Packet-switched Capacity Requirement Calculation

- Required IP system capacity calculated based on M/G/1 head of the line priority queue
- Mean throughput / mean delay requirements per Service Class as an input
- Question: What capacity C is needed to meet the requirements of the concurrent Service Classes?



Parameters of the model:

- λ_i : arrival rate of packets with priority i
- $\beta_i^{(i)}$: i-th moment of service duration of packets with priority I
- C: capacity searched for

T. Irnich, B. Walke: ***Spectrum Estimation Methodology for Next Generation Wireless Systems: Introduction and Results of Application to IMT-2000***. In *Proc. IEEE PIMRC 2005*, Berlin, Germany, September 2005.

Calculation of Spectrum Requirements and Adjustments

- Spectrum requirements = divide required capacity by **spectral efficiency** of IMT-Advanced System
- Account for multiple operators and minimum carrier bandwidths
- Sum spectrum requirements over co-existing radio environments and apply guard band adjustments
- Identify area with highest spectrum requirements
- Consider flexible use of spectrum by cognitive radios (weight factors)
- ITU-R M.1036 "Spectrum Estimation Methodology for IMT-Advanced Systems": 450 MHz needed. 464 MHz identified by WRC-07 in Nov. 2007

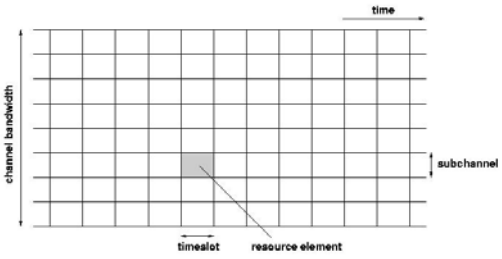
Main Characteristics of IMT-Advanced Systems

Main Characteristics of IMT-Advanced Systems

- **Orthogonal Frequency Division Multiplex (OFDM) to share the medium**
- **Orthogonal Frequency Division Multiple Access (OFDMA) for medium access**
- **Periodic MAC frame (known from ETSI / HiperMAN / IEEE 802.16 ~ WiMAX)**
- **Antenna Arrays at Base and Mobile Terminal**
- **Interference**
  - Coordination / Cancellation / Avoidance
- **Relay Enhanced Cells**
- **Simplified Network Operation**

OFDMA Subchannels and Resource Elements

- Transmission capacity as a Matrix
- Allocation of orthogonal Resource Elements possibl
- Multi dimensional REs
  - Time, Frequency
  - Code, Space
- Constraints
  - Parallel transmission ar reception on different subcarriers not possible
- Medium access control (MAC) is based on REs
  → optimal size of REs?



2-dimesional resource grid (time/frequency)

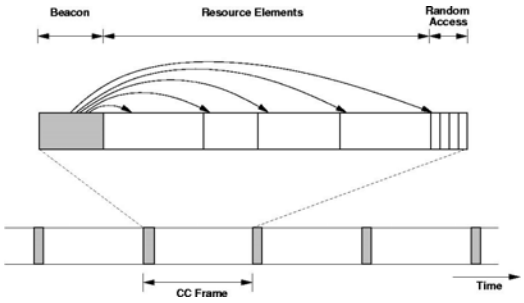
Centralized Medium Access Control

MAC concept

- Centralized resource request/grant scheme
- Used in IEEE 802.16, proposed for IEEE 802.11n

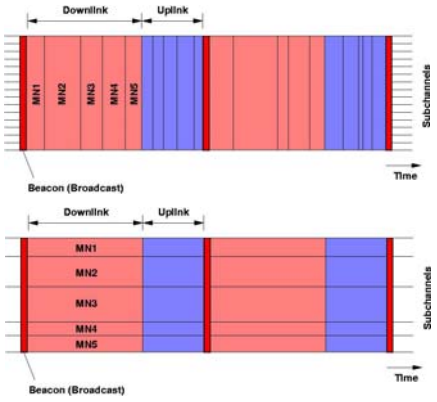
Frame structure

- Beacon (Broadcast)
  - Announcement of REs
- Random Access
  - Association, resource requests (RR), ACKs
- Resource Element
  - Transmission of data burst (PDU train)

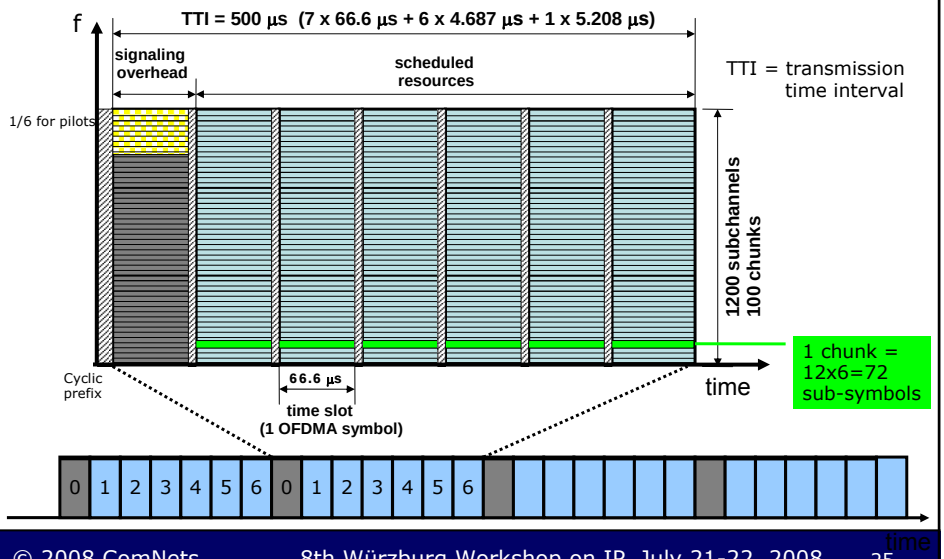


Resource Allocation in Single Hop Environment

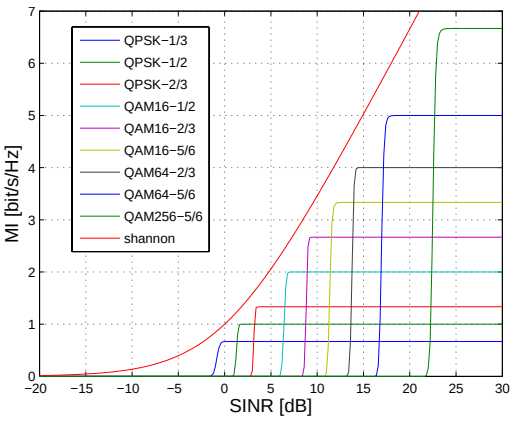
- TDMA / TDM
  - Frequency diversity across subchannels
  - Low power density burst transmission
- FDMA / FDM
  - Multi user diversity
  - Support of low cost terminals feasible



LTE TTI Frame (MAC Frame)



Link Adaptation: LTE DL PhyModes (MCS)



QAM256 is not in the standard proposals

Cell Capacity vs. Distance is Inverse to the Needs

Range of broadband base stations is limited
- high attenuation at high frequencies
- limited transmit power (EIRP limits)
- Unfavourable radio propagation conditions, e.g., in urban areas

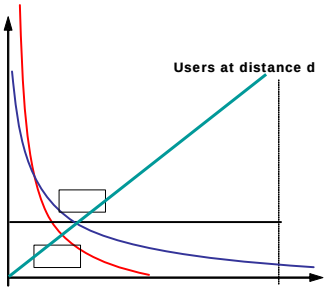
➔ Increased # of BS needed at increased carrier frequency to cover given area

➔ High CAPEX and OPEX (expenses)

➔ High cost/bit transmitted

➔ High data rate available close to AP only

With constant user density:
- Number of users increases with *d*
- Cell capacity per area element differs from capacity requested by users
- Technology trend worsens situation



Relay Enhanced Cell (REC):
→bring broadband to wider area than possible with single-hop cell
→reduce cost/bit transmitted by 2 to 3 orders of magnitude

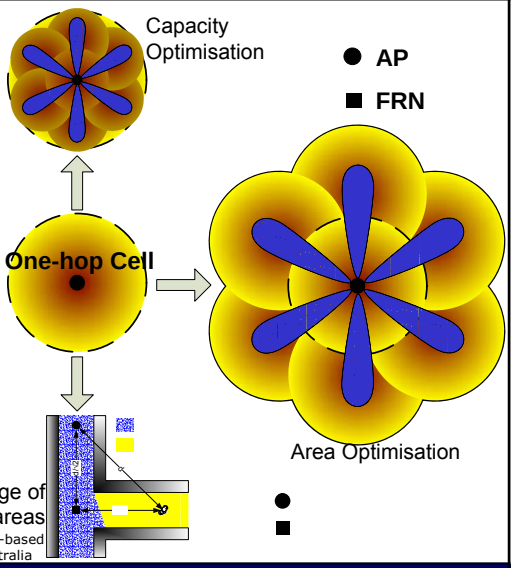
Sources:
B. Walke, H. Wijaya, D.C. Schultz: Relays in Infrastructure-based Future Mobile Radio Networks, VTC 2006 Spring, Melbourne, Australia
T. Irnich, D.C. Schultz, R. Pabst, P. Wienert: *Capacity of a Relaying Infrastructure for Broadband Radio Coverage of Urban Areas. Proc. 10th WWRF meeting, New York*, 10/2003

Layer-2 Relays for IMT-Advanced Systems

- Relay Enhanced Cells (in cellular)
- Mesh (in IEEE WLANs)

Relay Enhanced Cell (REC)
A cell complemented by Fixed Relay Nodes (FRN)

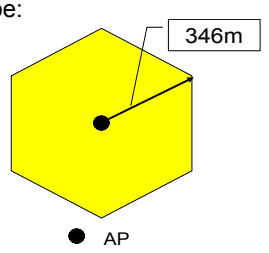
- Layer-2 Relays in REC
  - don't need a wired backbone access (low CAPEX and OPEX)
  - Full flexibility of relays (re-)positioning
  - enlarge the coverage area
  - Increase capacity at cell border
  - balance the capacity/area element
  - reduce transmission power and thereby co-channel interference
- Relays
  - Support fast network rollout
  - Allow outdoor to indoor service
  - Serve shadowed areas in REC
  - Exploit macro diversity
  - will be mass products

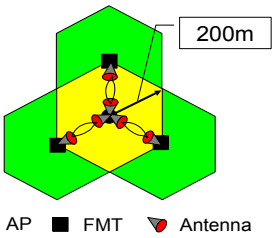


Source: B. Walke, H. Wijaya, D. Schultz: Relays in Infrastructure-based Future Mobile Radio Networks. VTC 2006 Spring, Melbourne, Australia

Single vs. 2-Hop – Cluster Order 7, 12 dB gain antenna

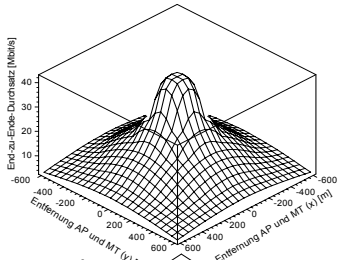
Cell type:

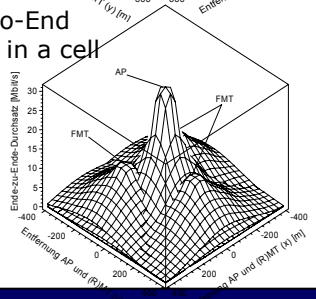




FMT =FRN

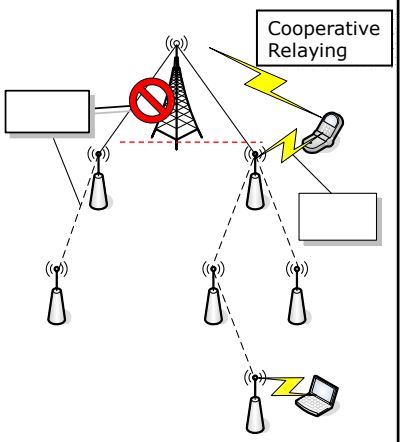
Max. End-to-End throughput in a cell





Layer-2 Relays in IMT-Advanced

- Layer 2 (Decode-and-Forward) relays are an inherent part of an IMT-Advanced systems
- Relay enhanced RRM technologies
  - Relays and multi-antenna technologies
  - Different modulation and coding schemes on relay and access link
  - Plug and play network roll out
- Tree topology, self-configuring nodes
  - Self healing: On demand re-organisation of the network topology
  - On demand meshing within REC
- Cooperative relaying as an option for capacity improvement

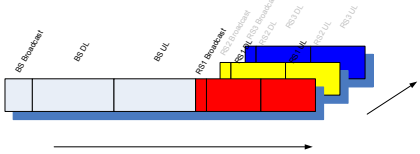


TDD Multi-hop Relay Principle

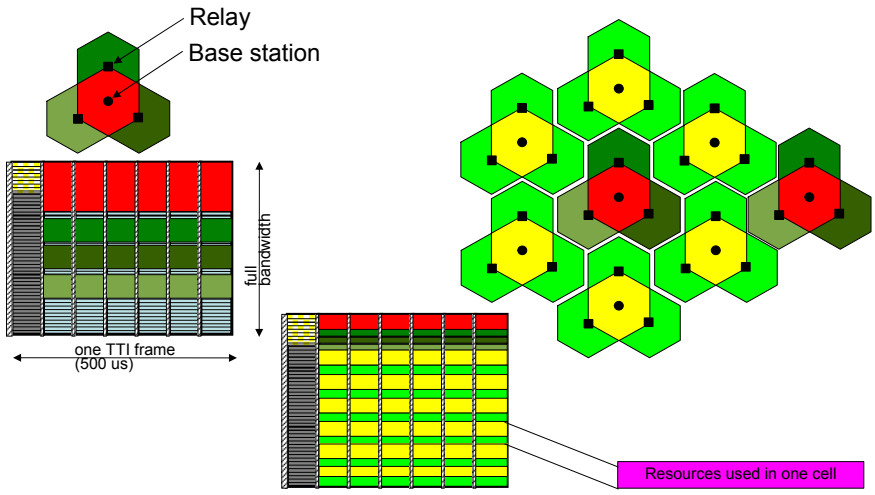
Two relay channel access schemes:

1. TD(R) channel access = relays transmit at different times and do not interfere each other

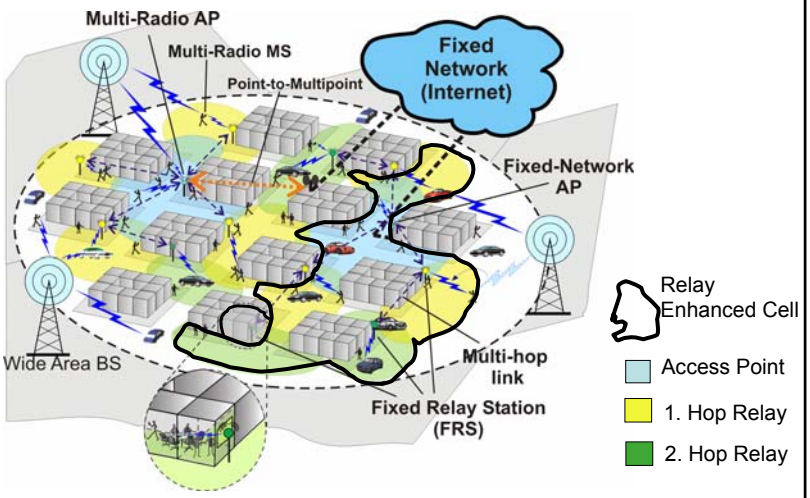
2. SD(R) channel access = spatially separated relays transmit at the same time



Inter/intra Cell Resource Management
Resource Separation in Frequency Domain(OFDMA)



IMT-Advanced System overlaid to 3G System



Walke, Bernhard; Pabst, Ralf; Schultz, Daniel C.: *A Mobile Broadband System based on Fixed Wireless Routers*. *Proc. ICCT 2003 Internat. Conf. Comm. Technologies*, Beijing, China 04/2003

Wireless / Mobile Systems Operations Philosophies

IT Community	Telco Community
-Sell terminals, subsidize services.	Sell services, subsidize mobile terminals.
-Certification once by WiFi/WiMAX Forum per device.	Certification done per device per operator.
-Web 2.0 model of operator business revenue: Operators rely on service providers to provide applications and share revenue. Operator revenue is limited to access.	Controlled market of services and contents. Walled garden concept. Complete Control. Limited applications due to limited and closed devices.
- Broadband pipe	Limited capacity pipe.
- Best effort service	Value added service.
- Internet architecture. Open mobile platforms	Reliable and secure service. Complex/expensive infrastructure (IMS).
- Inter working	
- Flat rate contract to ISP with unlimited data volume; Pay per use	Flat rate contract to mobile operator with volume tariffs; trend towards flat rate component.

Relay Based Cellular Networks

Conclusion

- IMT-Advanced has spectrum allocated
- IMT-Advanced Systems
  - OFDMA: resources in time, frequency and space
  - Coordination needed: intra- and inter-cell
  - Central vs. de-central resource control
- Standardization is in proceeding
- Relay enhanced cells are part of it (IEEE802.16j)
  - extend cell range
  - increase throughput at cell edge
  - is the name for Mesh in cellular
- Relays save Telco infrastructure cost

Thank you!

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