Wireless Broadband Networks

WLAN: Support of mobile devices, but low data rate for higher number of users

→ What to do for a high number of users or even needed QoS support?

Problem of the last mile

- Provide broadband Internet access to private buildings
- Modem, ISDN, xDSL, CATV (Cable TV), PLC (Power Line Communications) – everything needs a (costly) installation of cables

→ **WirelessMAN (WMAN)**

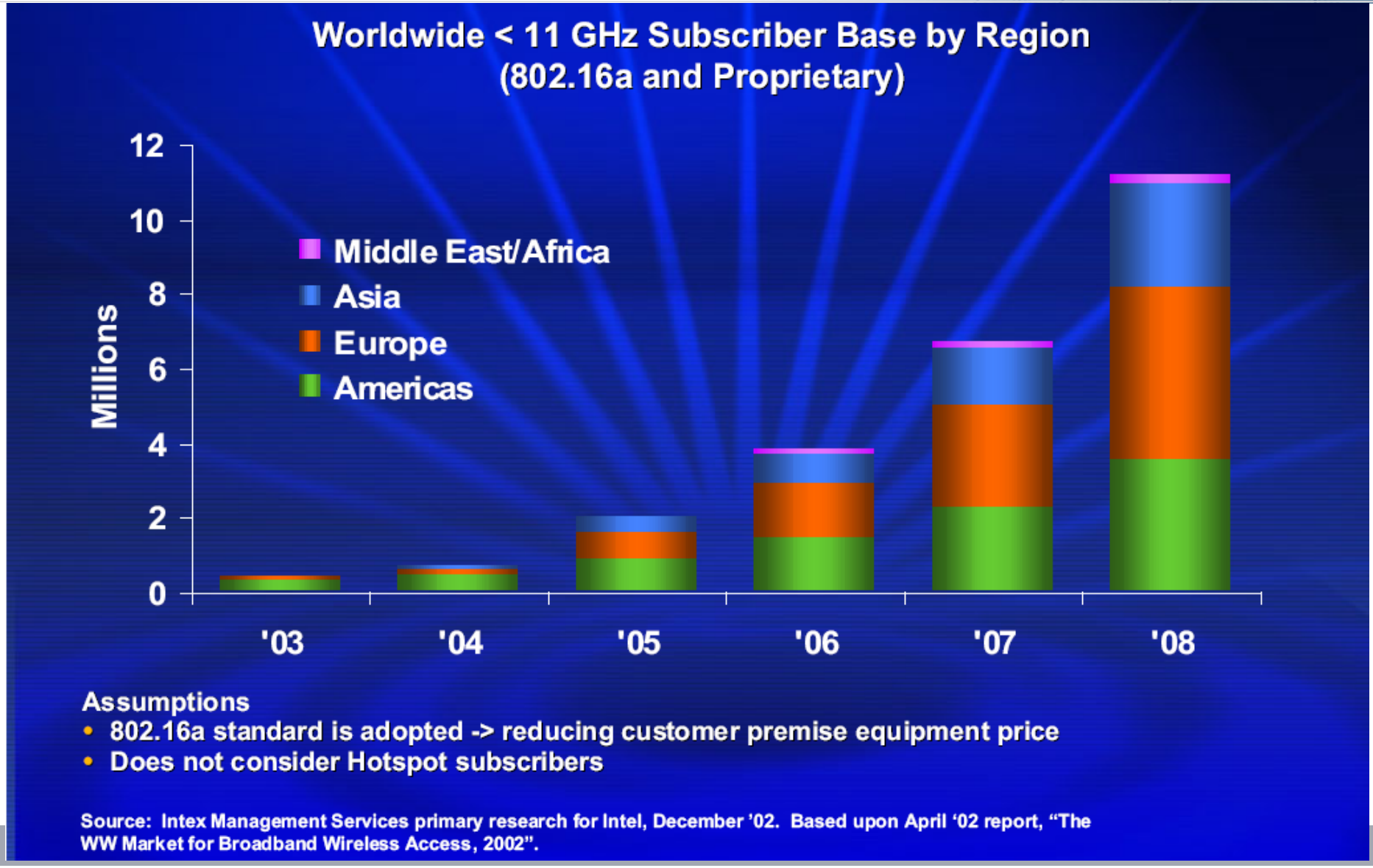
- Wireless Internet connection of hotspots
- High-speed Internet access for mobile users
- DSL replacement für residential areas and companies
- Wireless backbone

→ IEEE **802.16** (Broadband Wireless Access, BWA)

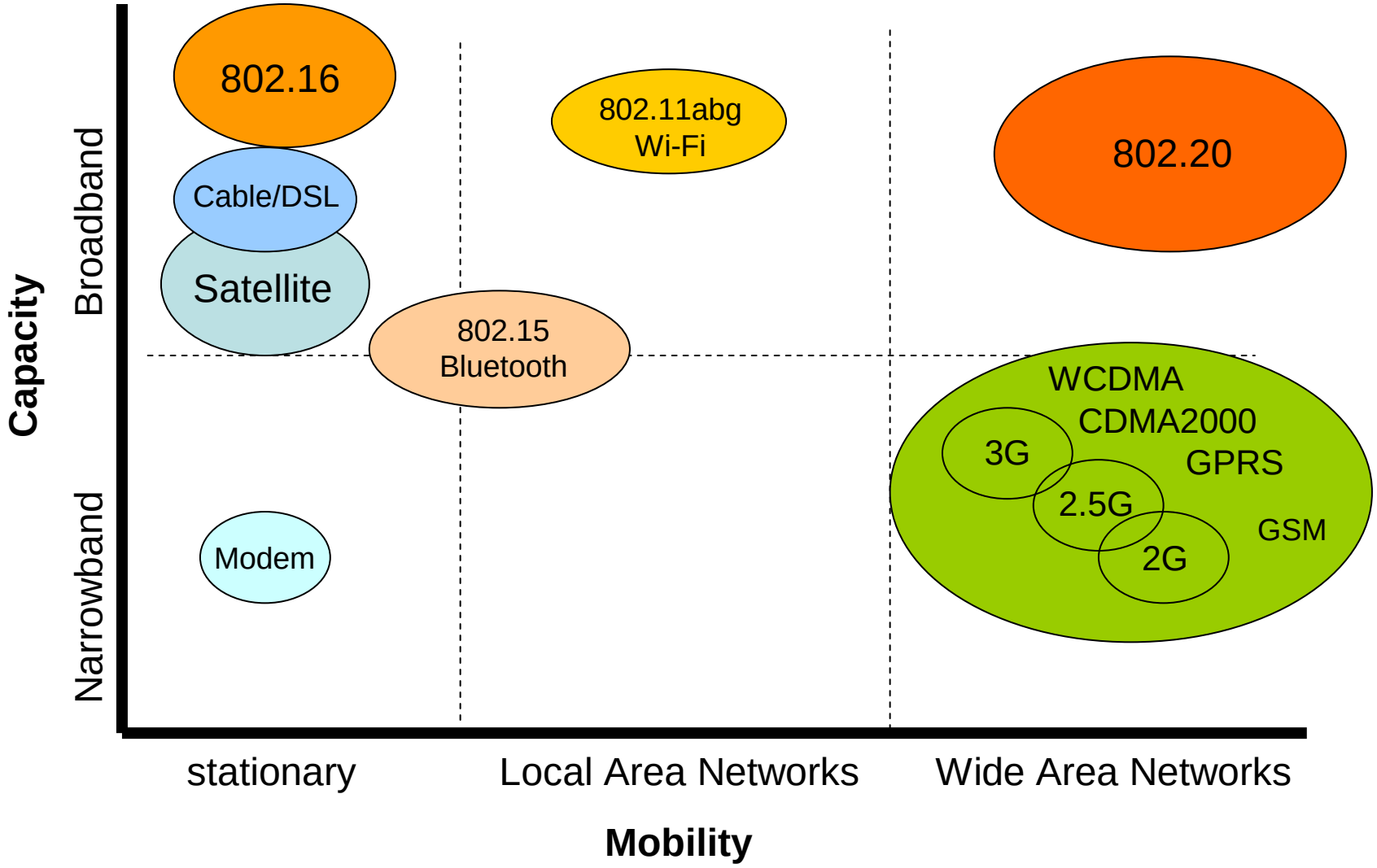
→ IEEE **802.20** (Mobile Broadband Wireless Access, MBWA)

→ IEEE **802.22** (Wireless Regional Area Network, WRAN)

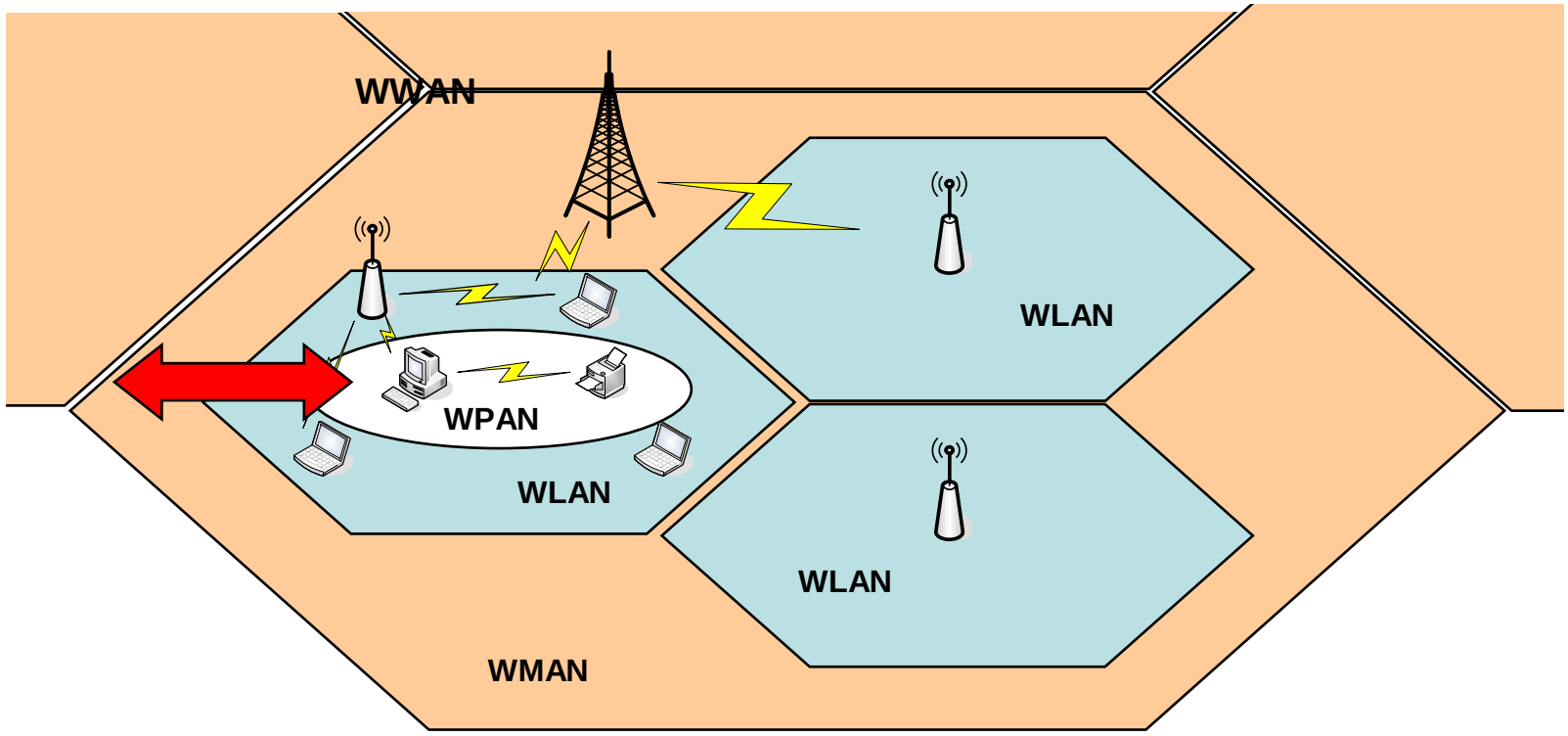
802.16 - Usage


Worldwide < 11 GHz Subscriber Base by Region
(802.16a and Proprietary)
Millions
12
10
8
6
4
2
0
Middle East/Africa
Asia
Europe
Americas
'03
'04
'05
'06
'07
'08
Assumptions
• 802.16a standard is adopted -> reducing customer premise equipment price
• Does not consider Hotspot subscribers
Source: Intex Management Services primary research for Intel, December '02. Based upon April '02 report, "The WW Market for Broadband Wireless Access, 2002".

Need for Speed

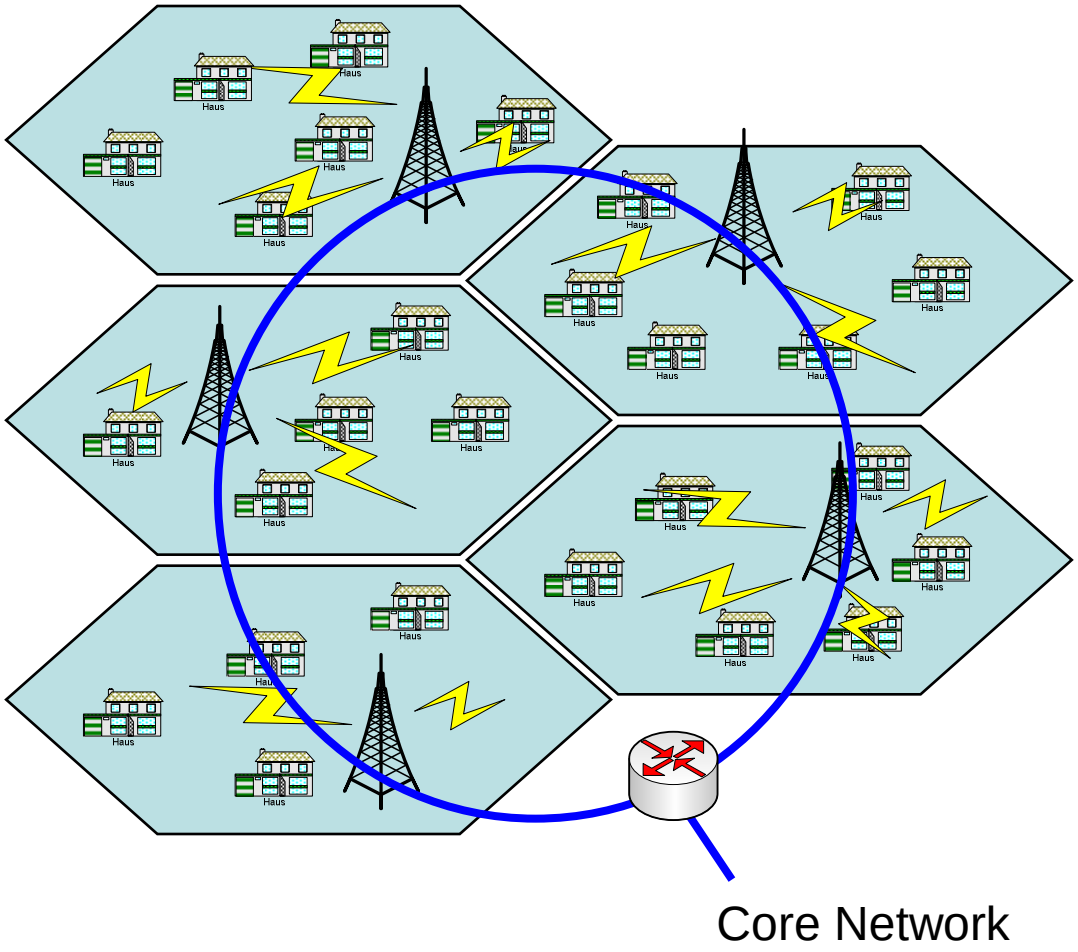


WMAN



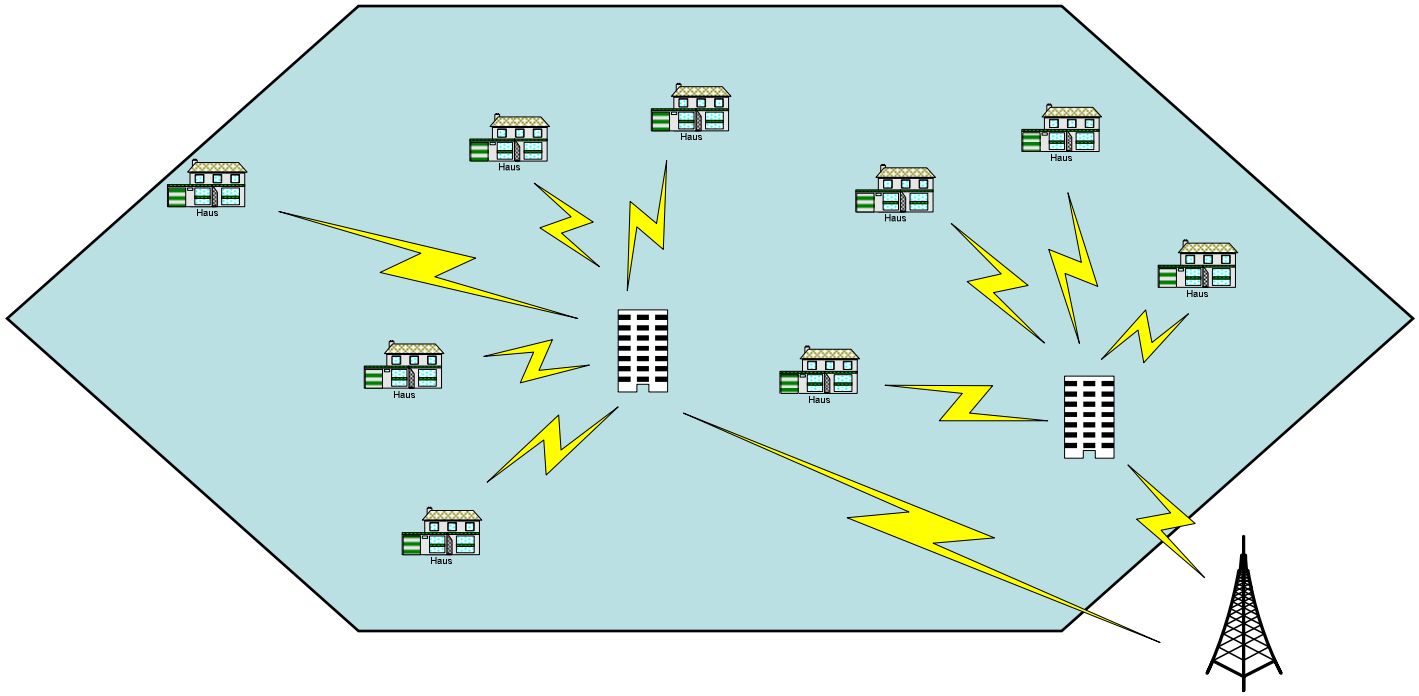
WPAN: IEEE 802.15 (WirelessPAN, Bluetooth)
WLAN: IEEE 802.11 (WirelessLAN)
WMAN: IEEE 802.16 (WirelessMAN)
WWAN: IEEE 802.16e (WirelessMAN), IEEE 802.20 (Wireless Mobility)
IEEE 802.21: Handover between the network types

802.16: Topology: Point-to-Multipoint



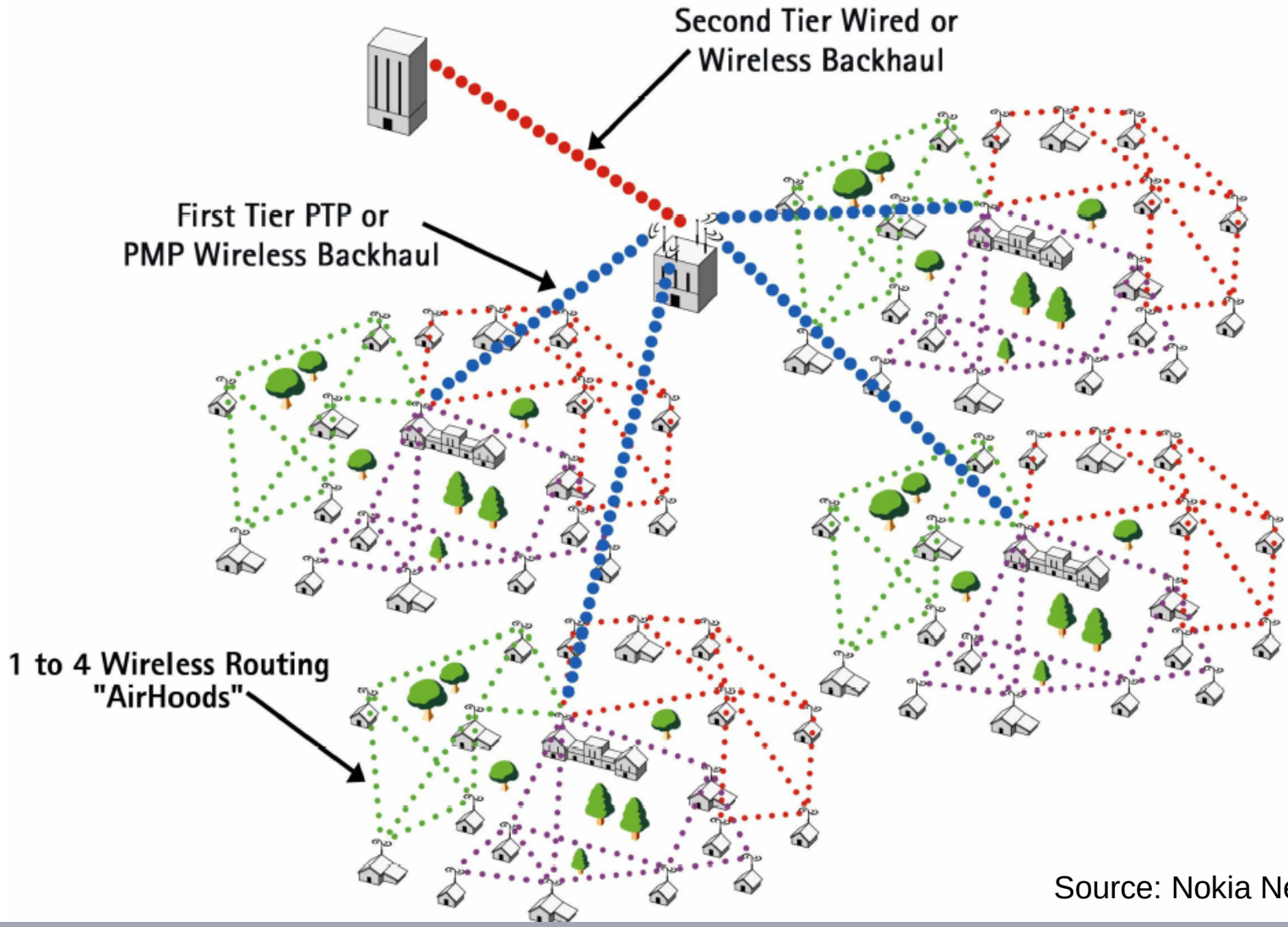
- A base station supplies a certain geographical area
- All base stations are connected to a fixed backbone network

802.16: Mesh Topology



- Designated subscribers serve as relay stations (repeater)
- A meshed network arises
- Good adaptation to geographical situation and bandwidth needs

Mesh Topology



Source: Nokia Networks

IEEE 802.16

Working group „Broadband Wireless Access“

- Founded July 1999
- Standard adopted December 2002
- Standardized as *WirelessMAN* (Europe: ETSI HIPERMAN)

Specification of PHY and MAC layer in 10 - 66 GHz

- Line-of-sight (LOS) necessary – low or no mobility
- Usage of license-free frequency bands as well as such which are subject to license
- Variable channel bandwidth for optimal usage of the frequency range
- Optimized for packet-oriented data communication
- QoS support
- Variable data rates

a, b, c, ...

IEEE 802.16.1

- Frequency range: 10 - 66 GHz
- Line-of-sight (LOS), up to 134 MBit/s

IEEE 802.16.2

- Minimization of the interference of coexisting WMANs

IEEE 802.16a

- Frequency range: 2 - 11 GHz
- Non-line-of-sight (NLOS, higher range, but lower data rate)
- Mesh topology

IEEE 802.16b

- Frequency range: 5 - 6 GHz („WirelessHUMAN“)

IEEE 802.16c

- Detailed System Profiles (interoperability)

IEEE 802.16d

- Combination of 16 and 16a with some modifications to PHY and MAC layer

IEEE 802.16e

- Support of mobility

IEEE 802.16f / g / i

- Management Information Base / Management Procedures and Services / Mobile Management Information Base

IEEE 802.16h

- Coexistence Mechanisms

IEEE 802.16j / k

- Multihop Relay Specification / MAC Bridging of 802.16

IEEE 802.16m

- Data rates of 100 Mbit/s (mobile) resp. 1 Gbit/s (fixed)

802.16, 802.16a, and 802.16e

	802.16	802.16a	802.16e
Frequency range	10 - 66 GHz	2 - 11 GHz	5 - 6 GHz
Transmission	LOS	NLOS	NLOS
Data rate	32 - 134 MBit/s	up to 75 MBit/s	up to 15 MBit/s
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM
Mobility	no	no	„pedestrian mobility“
Typical cell size	1.5 - 5 km ; 50 km is maximum size	7 - 10 km; 50 km is maximum size	1.5 - 5 km
Application area	Connection of stationary users of a region	Fast connection of hotspots, Mesh topology	Enhancement by user mobility

802.16 – Medium Access

IEEE 802.16 standard

- Defined is a so-called WirelessMAN-SC (Single Carrier) which means:
  - TDD (Time Division Duplex) or
  - FDD (Frequency Division Duplex) or
  - Half-Duplex FDD (cheaper)
- TDD und FDD variants realize a highly flexible duplexing schema: uplink and downlink bandwidths are dynamically assigned by adaptive modulation and coding, depending on the traffic requirements (DAMA-TDMA)

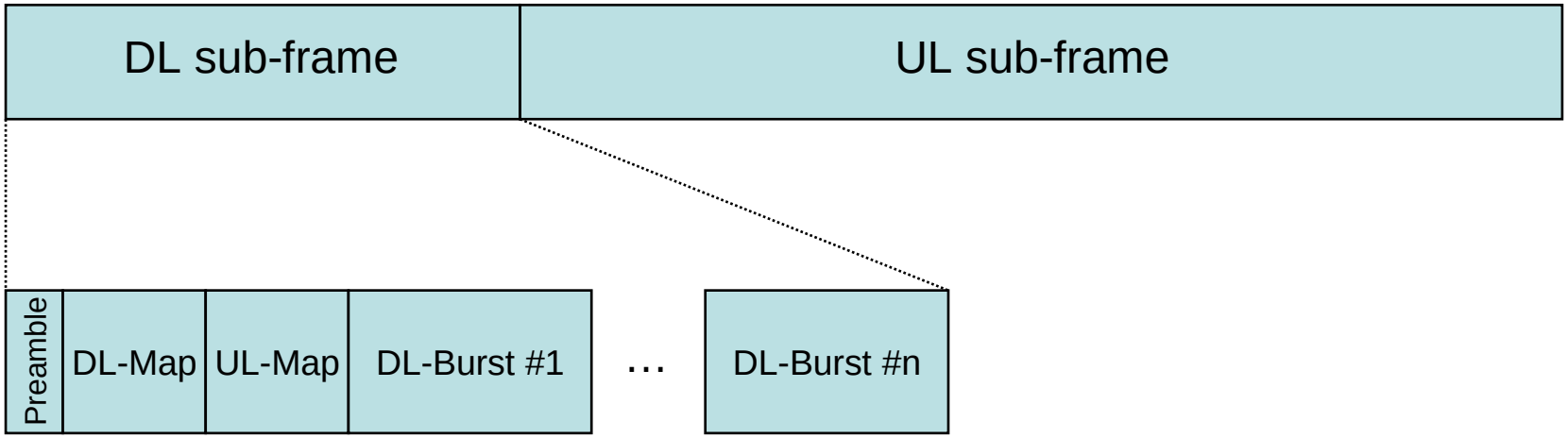
IEEE 802.16a

- Multipath signal propagation is to be considered
- Defined are three different transmission modes:
  - WirelessMAN-SC2 (adopted version from SC1)
  - WirelessMAN-OFDM on 256 sub-bands, access by TDMA (mandatory for license-free frequency bands)
  - WirelessMAN-OFDMA (OFD Multiple Access) on 2048 sub-bands; a transmission is assigned a subset of those sub-bands

IEEE 802.16e: WirelessMAN-OFDMA as well as a scalable version (SOFDMA)

Principle - TDD

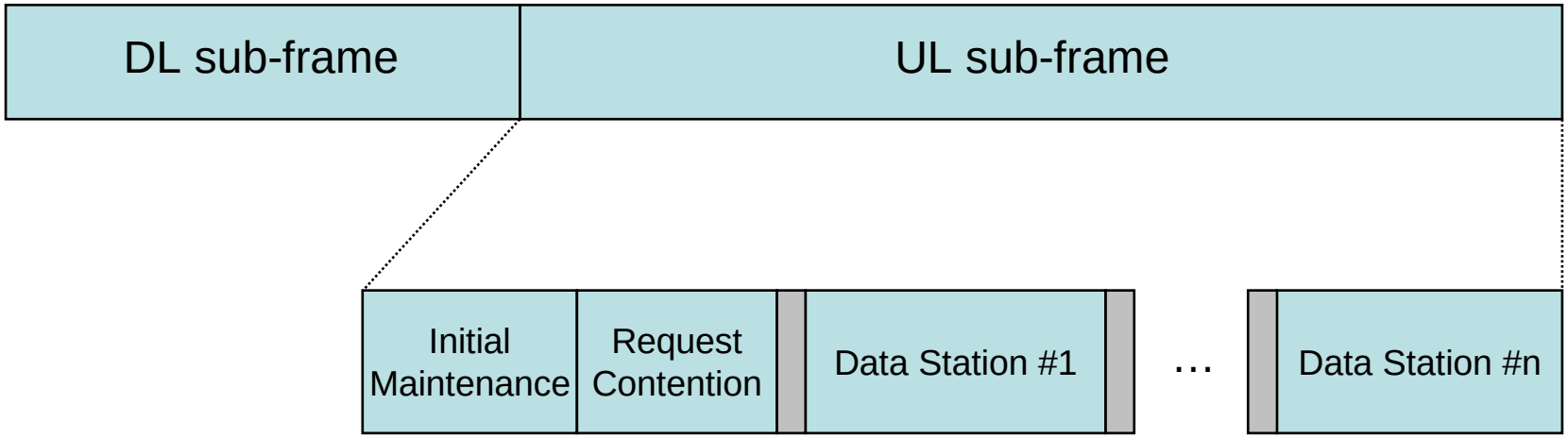
The whole time axis is divided into frames. a frame consists of an uplink (UL) sub-frame and a downlink (DL) sub-frame:



- Preamble: synchronization
- DL-Map: specifies changes in modulation and/or FEC schema which occur during the frame transmission
- UL-Map: notifies all stations about the bandwidth allocation for the following UL sub-frame
- DL-Burst: one or more MAC frames for a certain station

Frames in TDD

The whole time axis is divided into frames. a frame consists of an uplink (UL) sub-frame and a downlink (DL) sub-frame:



- Initial Maintenance: first access by stations to detect round-trip-time to the base station as well as necessary transmission power (random choice of a time slot in that field by backoff mechanism); collisions are possible
- Request Contention: demand reservations in coming UL maps (again by backoff mechanism), collisions are possible
- The following data re for several stations, as described in the UL map

802.16 – Transmission Control

- Scalability
  - The base station can manage several hundreds of stations
- Usage of flexible TDMA for medium access
- Dynamic frequency choice
- Support of different traffic types
  - Continuous data (video), bursty data (WWW)
- Provision of several levels of QoS
- Security mechanisms
  - Key management, authentication, encryption of payload
- Retransmissions, if necessary (ARQ)

802.16 MAC-Layer: QoS

- The MAC layer is connection-oriented!
- Four types of service classes are offered (like in ATM):
  - Unsolicited Grant Service (UGS)
  - Real-time Polling Service (rtPS)
  - Non-real-time Polling Service (nrtPS)
  - Best Effort Service (BE)
- Data of a connection are seen as a *Service Flow*

Service Classes

Unsolicited Grant Service

- Real-time transmission (e.g. voice), periodically transmission of fixed-length packets
- The base station reserves capacity in fixed time intervals

Real-Time Polling Service

- Real-time transmission (e.g. MPEG), periodically transmission of variable-length packets
- The base station initiates periodic polls to serve the bandwidth need of a receiver

Non-Real-Time Polling Service

- Variable-length packets with weak delay requirements
- The base station initiates polls frequently (but not necessarily periodically)
- Also could use Contention Requests

Best Effort Service

- No polling
- Stations use Contention Requests

Scheduling

To enforce QoS requirements, all transmission need to be scheduled

Centralized Scheduling

- The base station assigns capacity to the other stations

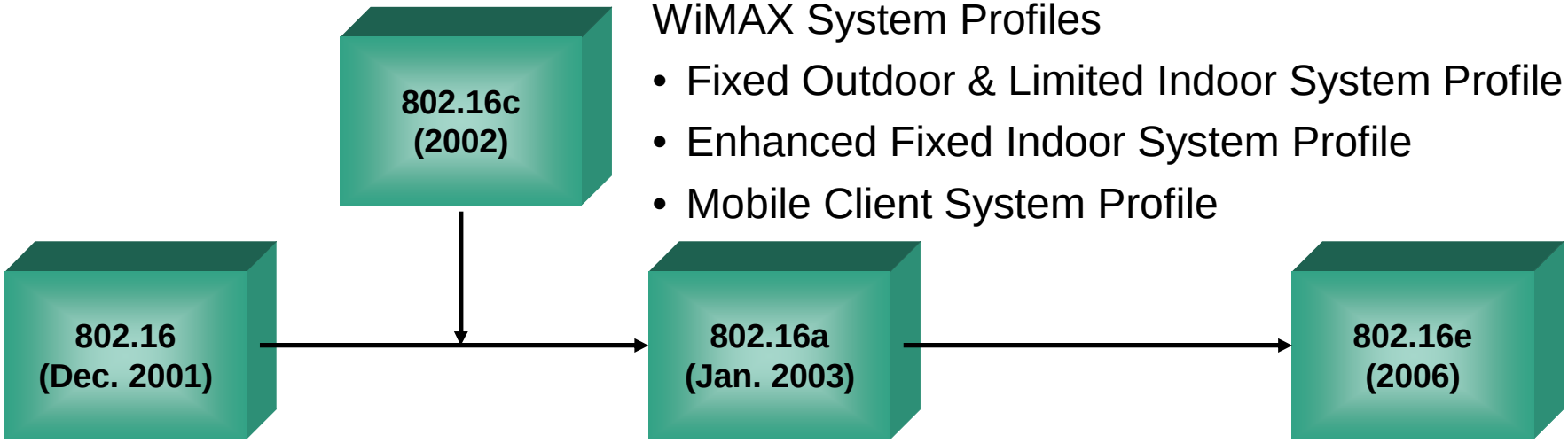
Decentralized Scheduling

- Stations exchange scheduling information with their neighbors
- Each station notes the scheduling request of the neighbors
- The base station is not longer involved in scheduling, it only assigns bandwidth
- *Variant 1: Coordinated*. The base station reserves bandwidth for the exchange of scheduling messages (with a 3-Way-Handshake)
- *Variant 2: Uncoordinated*. Exchange of scheduling messages in done with a contention mechanism (using a backoff) – risk of collisions

802.16c-Forum (WiMAX)

Worldwide Interoperability for Microwave Access Forum (WiMAX)

- Members: Airspan Networks, Alvarion, Aperto Networks, Ensemble Communication, Fujitsu of America, Intel, Nokia, Proxim, Wi-LAN
- Goal: global compatibility between 802.16a-Produkten by definition of profiles



WiMAX System Profiles

- Fixed Outdoor & Limited Indoor System Profile
- Enhanced Fixed Indoor System Profile
- Mobile Client System Profile

- 10 - 66 GHz
- LOS
- Point-to-point

- 2 - 11 GHz
- NLOS
- Point-to-multipoint

- 2 - 6 GHz
- Mobility up to speed of vehicles
- Roaming

802.16 vs. 802.11

	802.11	802.16	Explanation
Range	• 30 - 100 Meter	• Typical cell size: 7 - 10 km • Up to 50 km • No Hidden Stations	• 802.16 handles multipath propagation much better – signal quality in larger distances I still good
Target usage	• Indoor	• Outdoor, Support of mesh topologies	
Scalability	• Bandwidth of 20 MHz is fixed	• Bandwidth between 1.5 and 28 MHz allows an adaptation to the users	• 802.16 has no problem with overlapping cells, usage of DAMA-TDMA instead of CSMA/CA, adaptive modulation possible
Data rate	• Up to 54 MBit/s	• Up to 134 MBit/s, depending on assigned bandwidth	• OFDM with higher modulation ratio, net data rate also is higher (due to DAMA)
QoS	• Only with 802.11e	• Differentiated Services	• Reservation of capacity allows several service classes
Costs	• License-free	• License-free as well as licensed bands	• Costs are accepted in 802.16 – Alternative to xDSL

IEEE 802.20

„Mobile Broadband Wireless Access“ (MBWA)

- Since December 2002 independent IEEE working group 802.20
- Before, part of 802.16 as ECSG (Executive Committee Study Group)
- Still work in progress, but similar to 802.16e

Specification of PHY- and MAC layer:

- Focus on data communications, especially IP-based services, e.g.
  - Intranet of a company, VLAN Services
  - Games and entertainment
  - Internet and location-based services
- Support of different service classes (including real-time)
- Data rates as for ADSL: Downlink > 1 MBit/s, Uplink > 300 KBit/s
- Mobility support for speeds up to 250 km/h
- World-wide roaming by Mobile IP

Integration in 3G networks (UMTS)

Vision: 2009 30 Million participants should use 802.20

802.20 (Wireless Mobility)

- 802.20 is a competitor to 3G Wireless Cellular Networks/UMTS. Main question here: CDMA or OFDM?
- 802.20 is specified for 500 MHz up to 3.5GHz
- Packet-based network
- 802.20 interface:
  - Real-time transmission
  - Wireless networking of whole cities
  - Competitor to 802.16, DSL and cable links (more than 1MBit/s)
  - Cell size up to 15 km
  - Mobile usage possible up to 250 km/h
  - E.g. usable in high-speed trains
- Maybe in future: Combination of 802.11, 802.16, 802.20 for a mobile Internet

802.20 vs. 802.16

802.16

- Originally for fixed stations, frequencies: 10-66 GHz, bandwidth per channel: 20-28 MHz
- Enhancement 802.16a: 2-11 GHz, Bandwidth per channel ~ 6 MHz
- Mobility only with 802.16e, basing on PHY/MAC of 802.16a, for lower speeds, regional roaming

802.20

- Designed for mobile stations, frequencies lower than 3,5 GHz, bandwidth per channel in FDD: 1.25 MHz up/down, in TDD: 5 MHz
- New PHY und MAC layer, handover between cells and cell sectors with different mobility classes up to 250 km/h, world-wide roaming

Possible Technologies for Hotspots

Standard	Bit rate	Range	Mobility	Costs	Available from…
802.11 (a, b, g)	1 - 54 MBit/s	100 m	Walking speed	Ca. 13% of the costs of a UMTS cell	Since years
802.16 (a, e)	Up to 134 MBit/s	Up to 50 km	120 - 150 km/h (cars, trains)	20% of the costs of a UMTS cell	USA - 2004 EU - 2005
802.20	Up to 1 MBit/s	Up to 15 km	Up to 250 km/h (high-speed trains)	n/a	200x???

802.20 und 3G (UMTS)

3G (UMTS)

- Relatively low spectral efficiency and relatively low number of users per cell with current CDMA technology
- Circuit-switched access- und core network, optimized for constant data rates (voice), not optimal for data services
- Transmission principle unsuitable for TCP because of relatively high error rate and slow error correction
- Relatively high costs by expensive 3G-infrastruktur
- Data rates of 144 KBit/s for 100 km/h

802.20

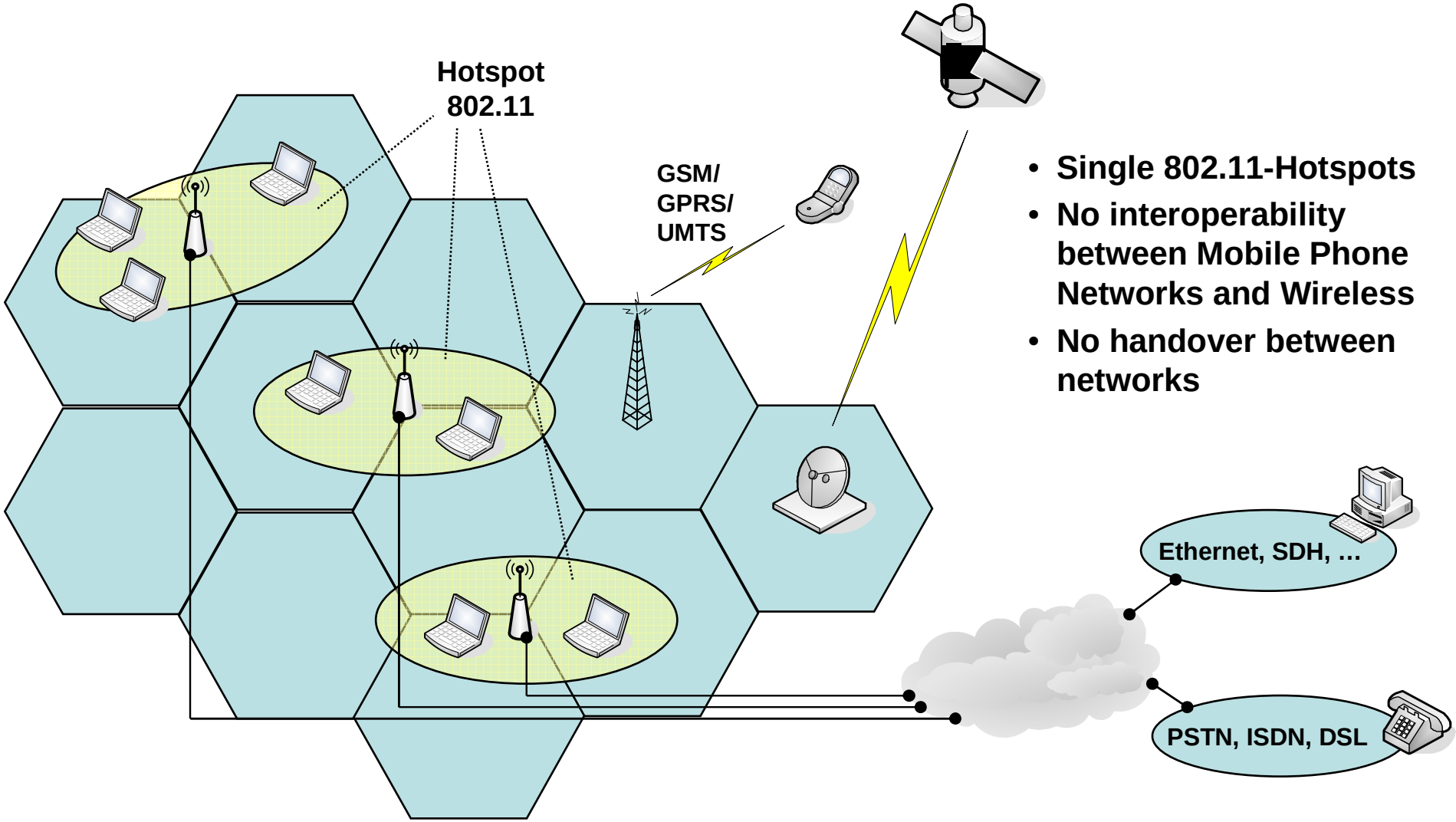
- Higher spectral efficiency and more users per cell because of OFDM tchnology
- Only packet switching (IP), also for voice services (Voice over IP), efficient usage of bandwidth also for varying data rates
- Transmission suited for TCP by using FEC together with fast ARQ
- Relatively low costs by “flat” IP-based architecture
- Data rates of 1 MBit/s for 250 km/h

IEEE 802.22 – WRAN

Relatively new standard – working group formed in 2004, but only general specification:

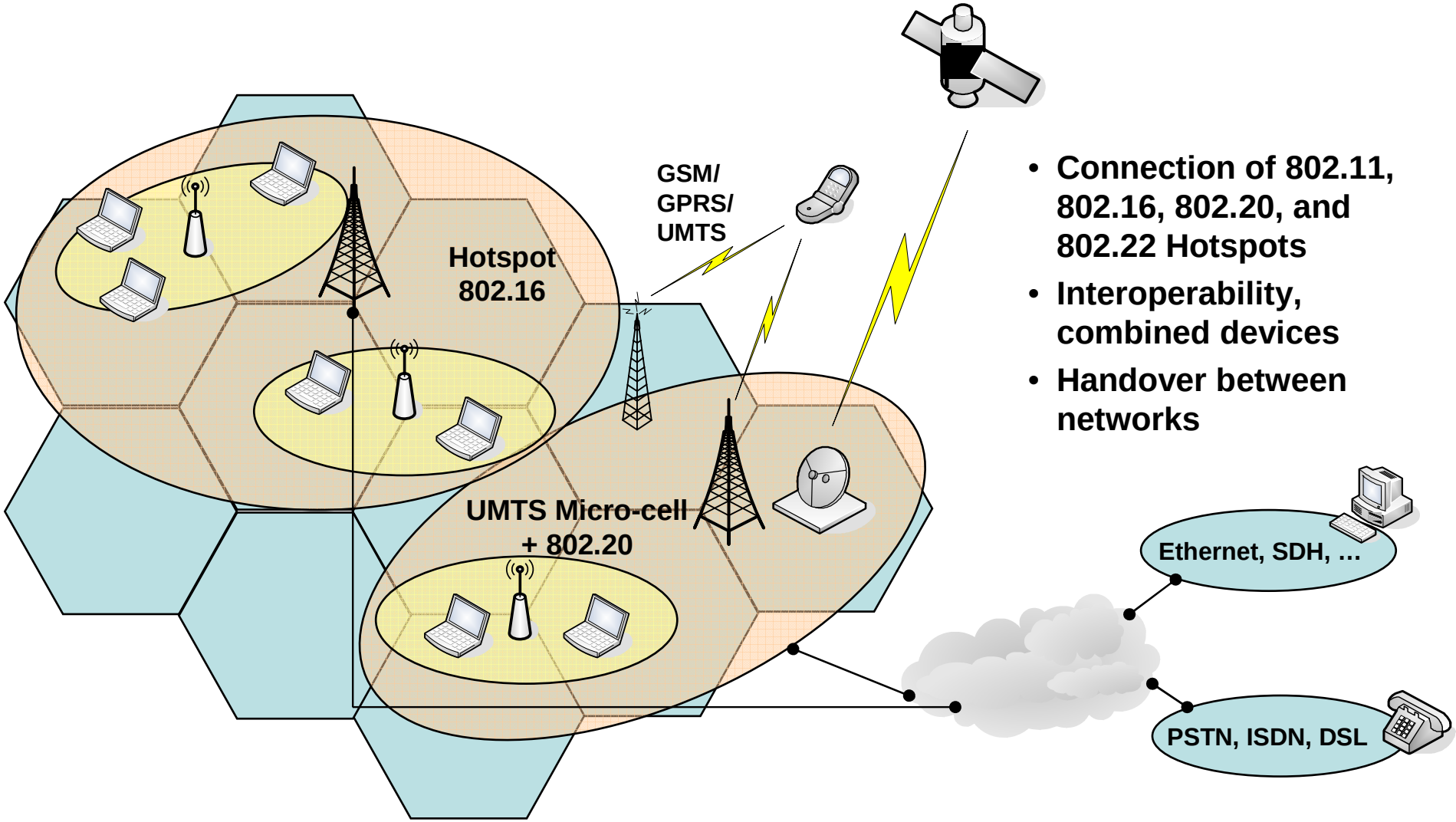
- Deploy wireless regional area networks using unused TV channels between 54 and 862 MHz without interfering with the licensed services now operating in the TV bands – alternative for regions in which DSL and WiMAX are not profitable
- PHY layer: FDD/OFDMA with QAM-64
  - By using just one TV channel (a TV channel has a bandwidth of 6 MHz, in some countries they can be of 7 or 8 MHz) the approximate maximum bit rate is 19 MBit/s at a 30 km distance
- MAC layer: cognitive protocol for point-to-multipoint network
  - A base station ensures that no harmful interference to the licensed incumbent services in the TV broadcast bands is caused by sensing unused frequencies
  - A base station could be equipped with a GPS receiver which would allow its position to be reported – so, based on the location, channels can be chosen
  - Or: the base station lets its customers sense the whole bandwidth, i.e. distributed sensing is done to decide about possible frequencies.
- But: only in early development

Conclusion: 4G and Hotspots Today



- Single 802.11-Hotspots
- No interoperability between Mobile Phone Networks and Wireless
- No handover between networks

Hotspots Tomorrow?



- Connection of 802.11, 802.16, 802.20, and 802.22 Hotspots
- Interoperability, combined devices
- Handover between networks