EC 551
Telecommunication System Engineering

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Syllabus

- Tentatively

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Week 3	**OFDM and modulation techniques**
Week 4	Coding techniques in wireless systems
Week 5	**WiMax Physical Layer**
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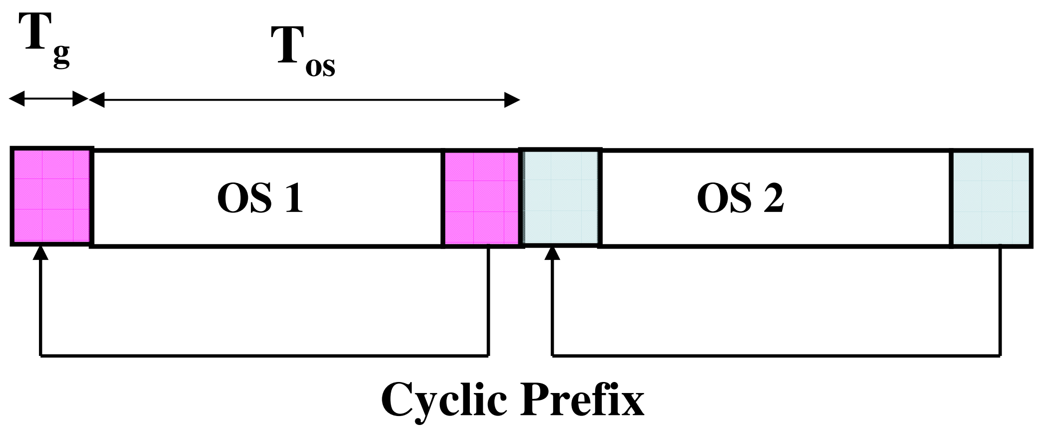
Week 11	GSM System
Week 12	GPRS System
Week 13	UMTS
Week 14	IP networks
Week 15	VOIP

Cyclic Prefix Illustration



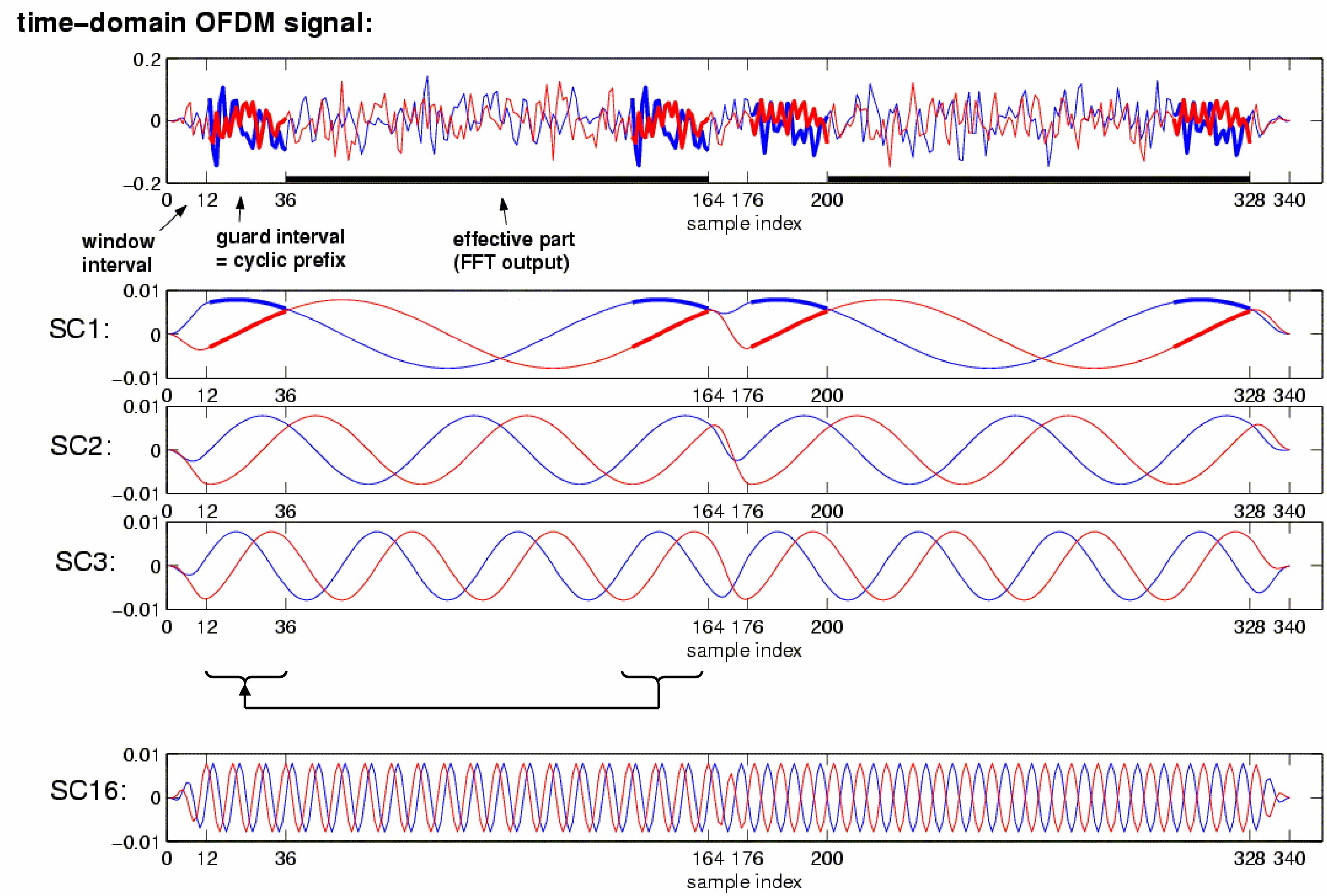
OS1,OS2 - OFDM Symbols

T_g - Guard Time Interval

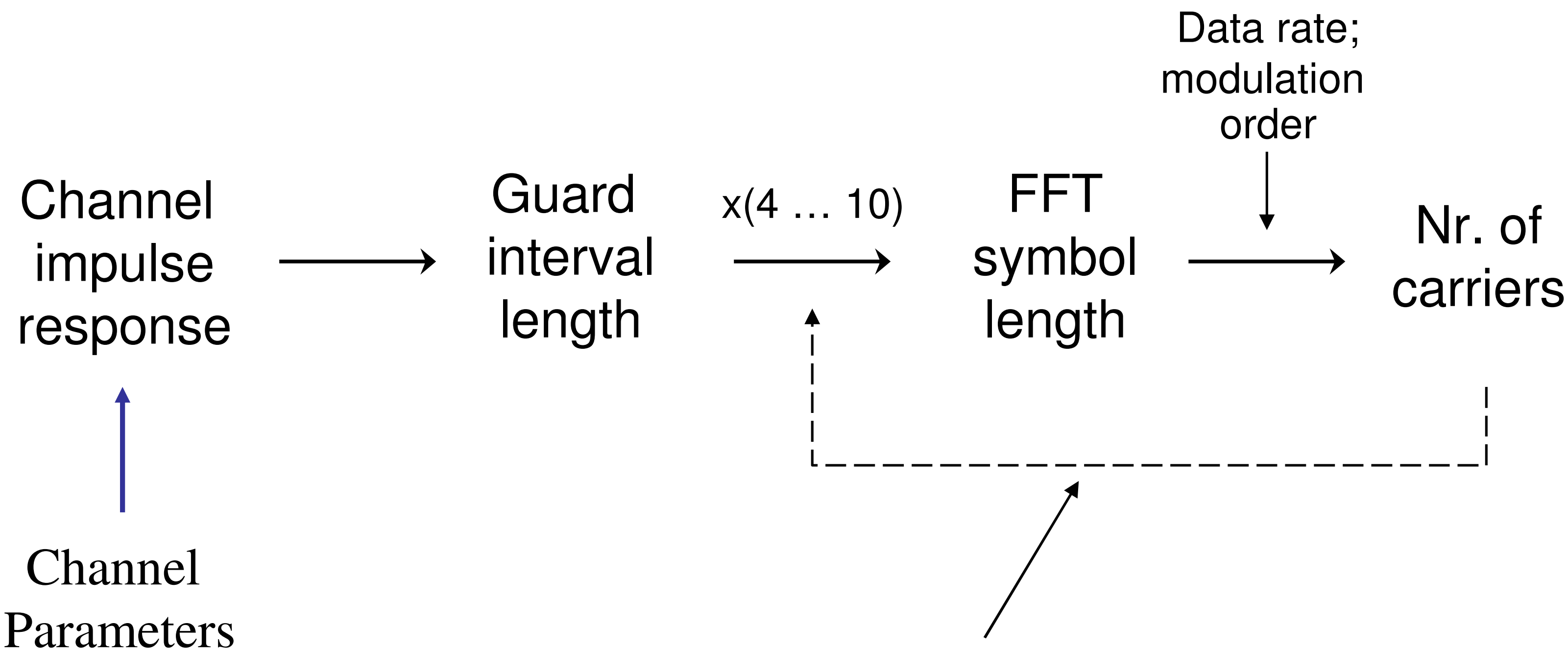
T_s - Data Symbol Period

T_{os} - OFDM Symbol Period - $N * T_s$

Guard interval (2) - Cyclic extension



Design of an OFDM System



Other constraints:

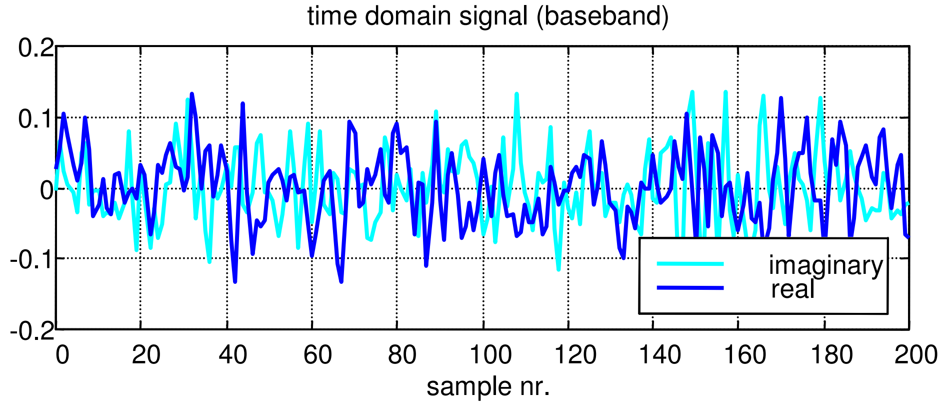
- Nr. of carriers should match FFT size and data packet length
- considering coding and modulation schemes

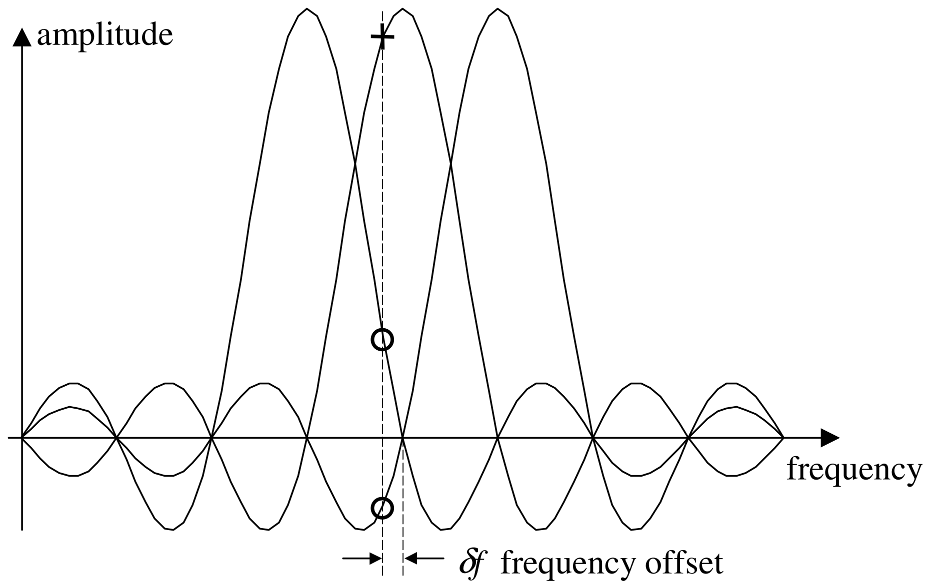
Advantages of OFDM

- Solves the multipath-propagation problem
  - Simple equalization at receiver
- Computationally efficient
  - For broadband systems more efficient than SC
- Supports several multiple access schemes
  - TDMA, FDMA, MC-CDMA, etc.
- Supports various modulation schemes
  - Adaptability to SNR of sub-carriers is possible

Problems of OFDM (Research Topics)

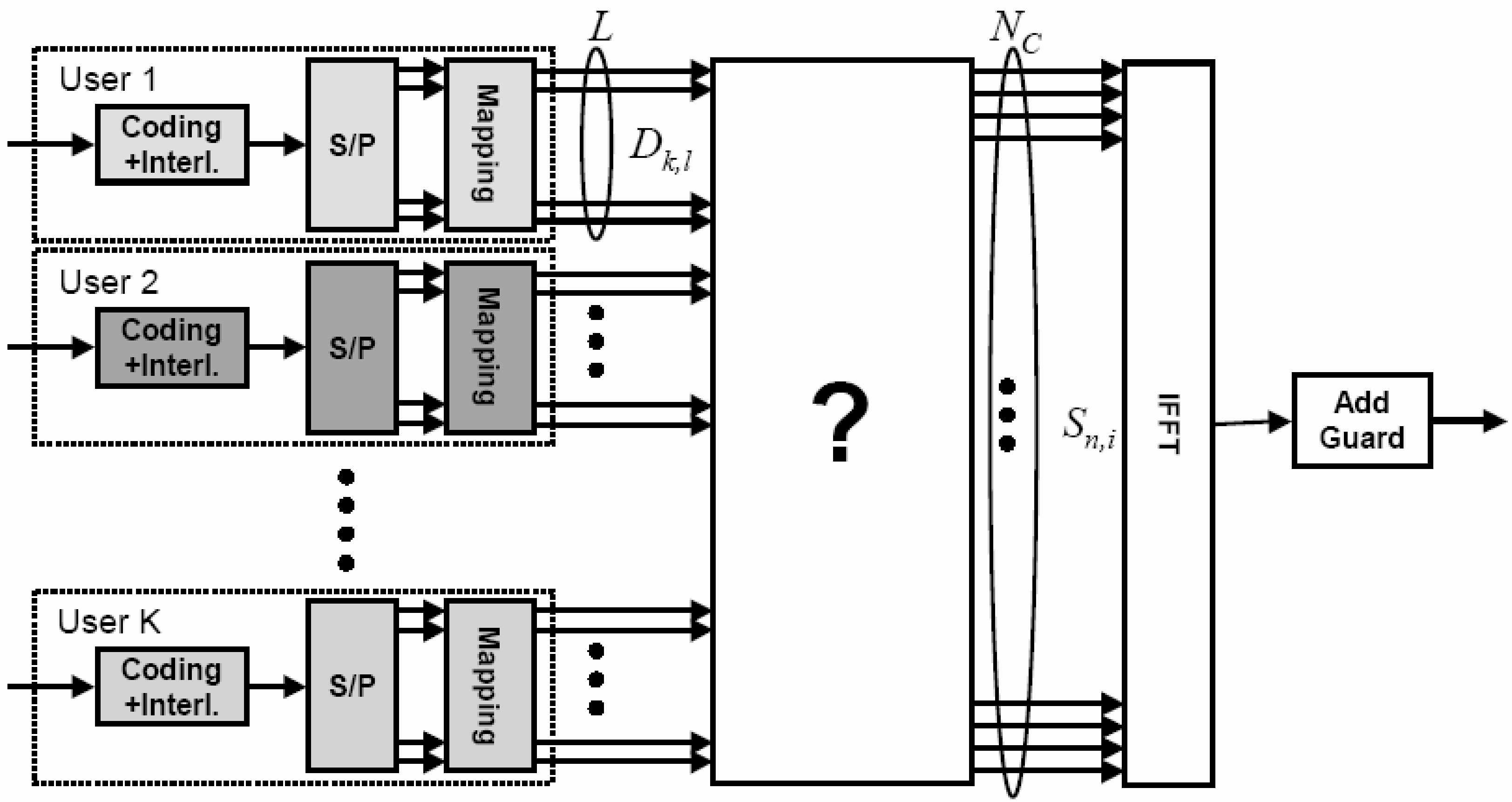
- Synchronization issues:
  - **Time synchronization**
    - Find start of symbols
  - **Frequency synchr.**
    - Find sub-carrier positions
- Non-constant power envelope
  - Linear amplifiers needed
- Channel estimation:
  - To retrieve data
  - **Channel** is **time-variant**





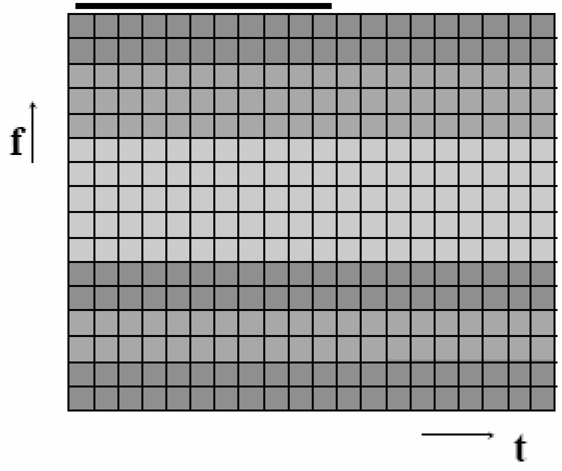
OFDM for Communication Systems

For a given OFDM system find a suitable multiple access scheme that maps the user data to a modulation block !

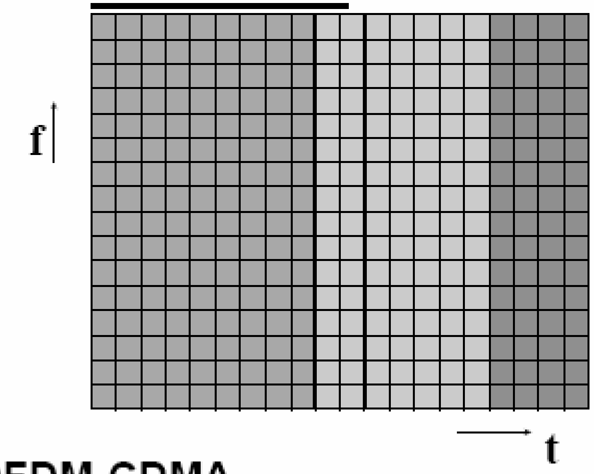


OFDM Multiple Access Schemes

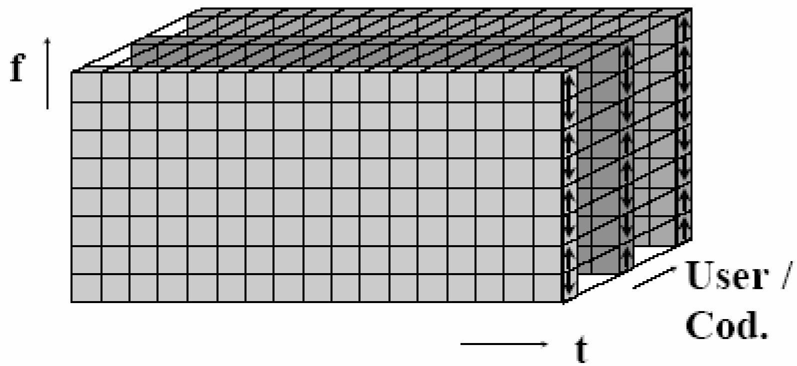
OFDM-FDMA



OFDM-TDMA



OFDM-CDMA



WIMAX Technology

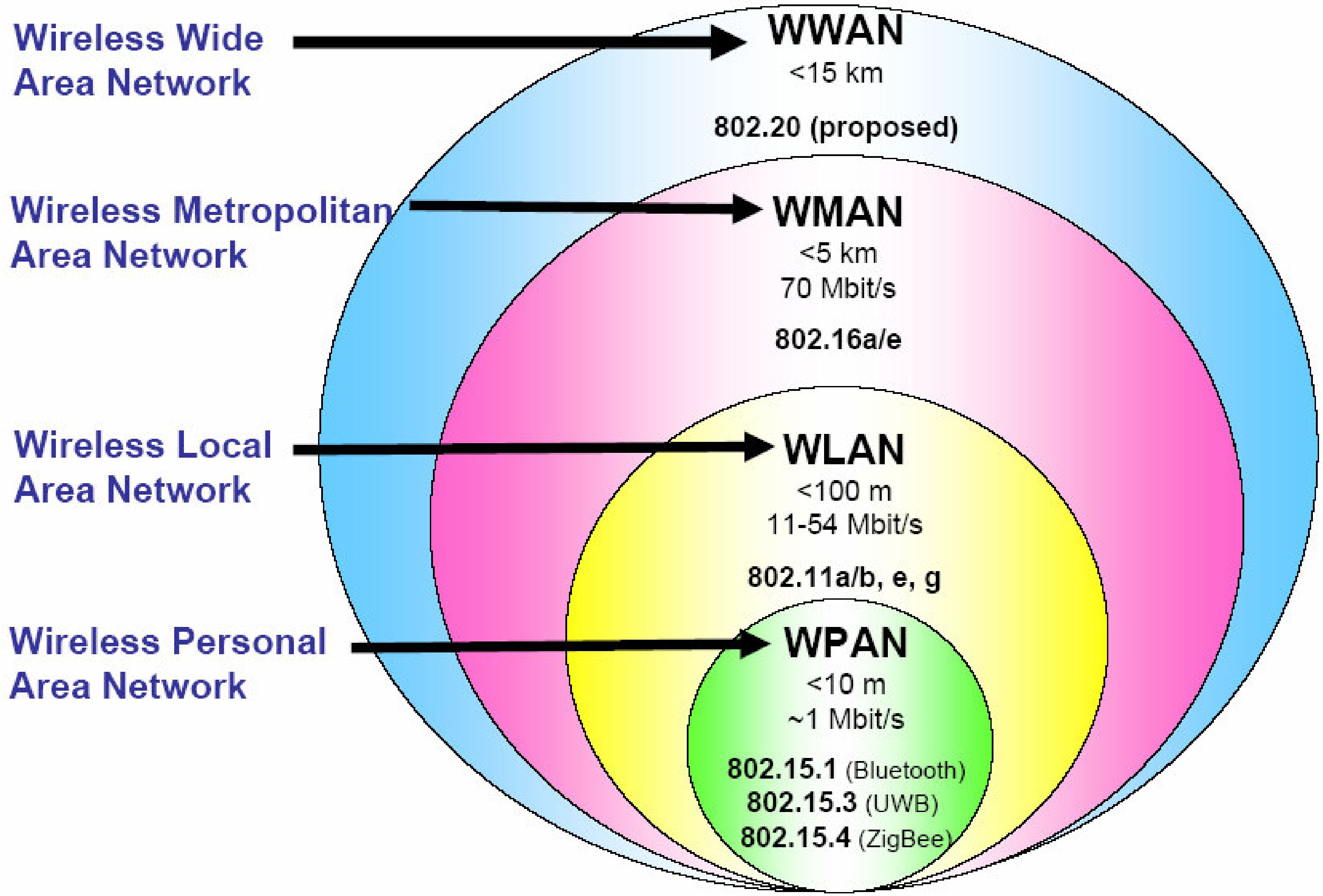
- WIMAX stands for **Worldwide Interoperability for Microwave Access**
- WiMAX refers to broadband wireless networks that are based on the IEEE 802.16 standard, which ensures compatibility and interoperability between broadband wireless access equipment
- WiMAX, which will have a range of up to 50 km, is primarily aimed at making broadband network access widely available without the expense of stringing wires

IEEE 802.16

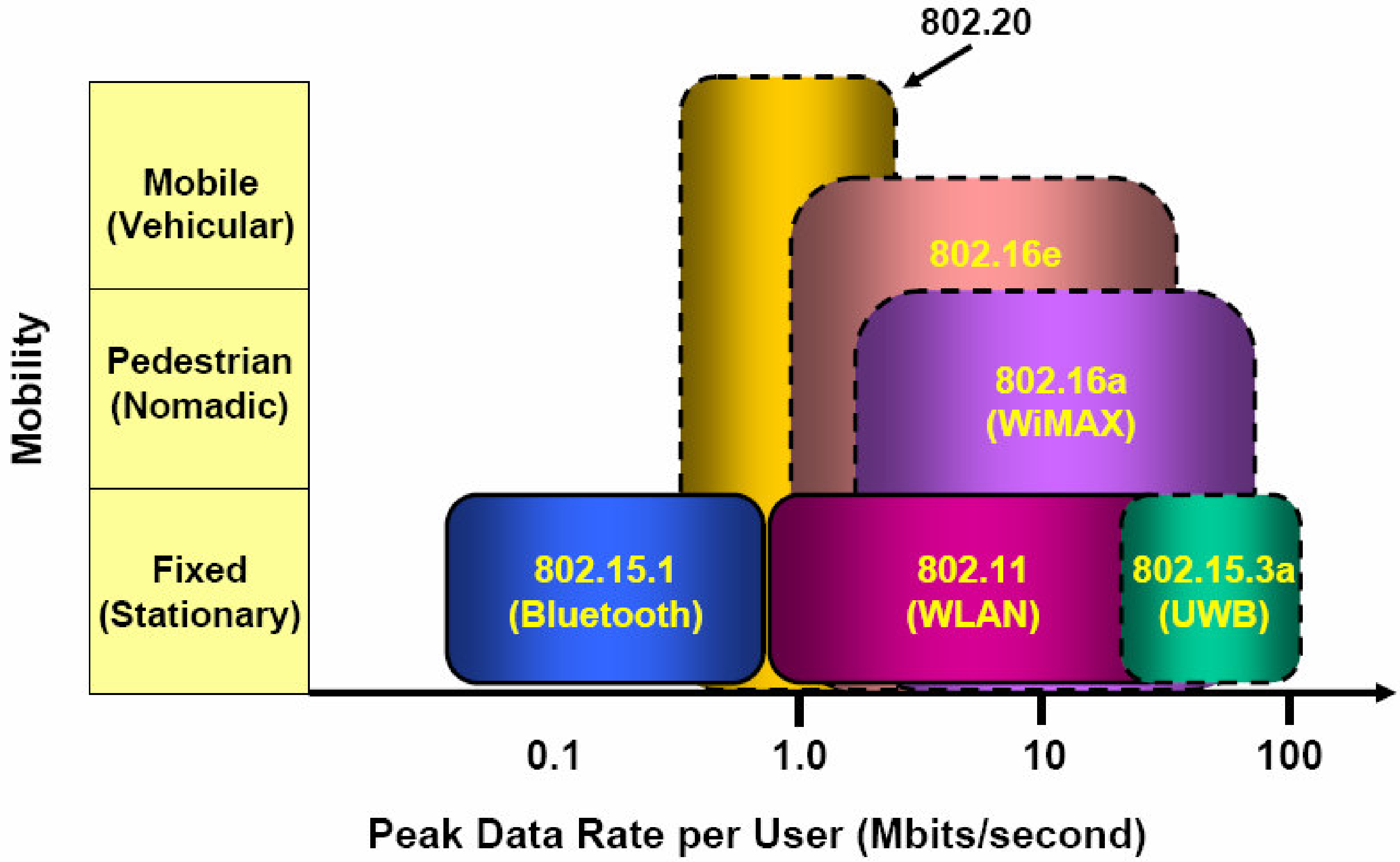
The standard IEEE 802.16 defines the air interface, including the MAC layer and multiple PHY layer options, for fixed Broadband Wireless Access (BWA) systems to be used in a Wireless Metropolitan Area Network (WMAN) for residential and enterprise use. IEEE 802.16 is also often referred to as WiMax. The WiMax Forum strives to ensure interoperability between different 802.16 implementations - a difficult task due to the large number of options in the standard.

IEEE 802.16 cannot be used in a mobile environment. For this purpose, IEEE 802.16e is being developed. This standard will compete with the IEEE 802.20 standard (still in early phase).

Wireless Communication Networks



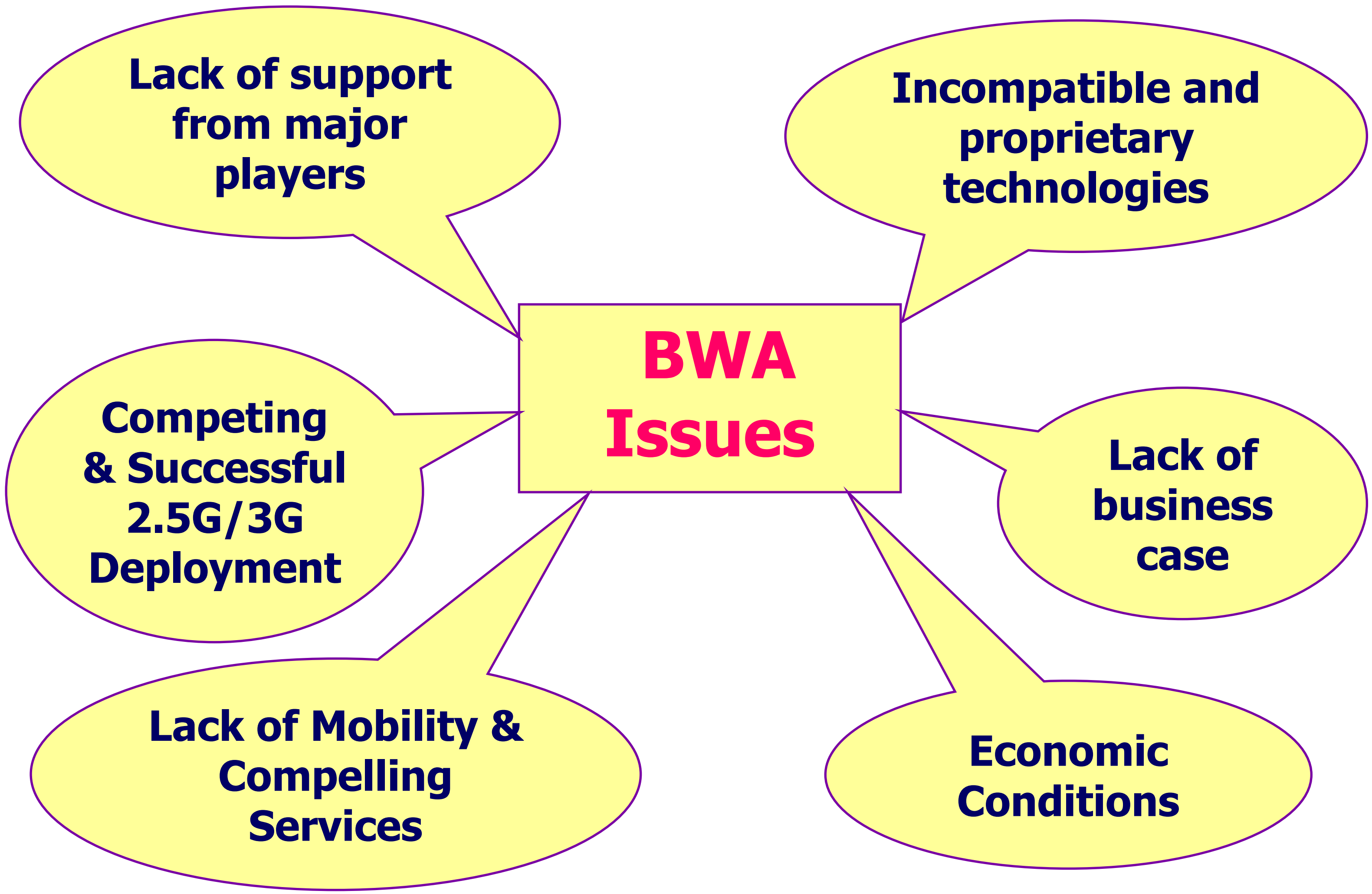
Peak Data Rate



ITU Definitions

- **Fixed wireless access (FWA)**
  - Wireless access application in which the location of the end-user termination and the network access point to be connected to the end-user are fixed.
- **Mobile wireless access (MWA)**
  - Wireless access application in which the location of the end-user termination is mobile.
- **Nomadic wireless access (NWA)**
  - Wireless access application in which the location of the end-user termination may be in different places but it must be stationary while in use.

Why hasn't BWA taken off?



At least 40 different incompatible solutions on the market.

802.16/WiMAX – Best of BWA

Open standards based network

Support from major industry players

802.16/WiMAX

Support for Mobility & Next Generation services

Support for high data rates

IEEE 802 Committee

Physical Layer
- RF, Power, Modulation, Coding
- Fixed and Mobile

MAC Layer
- Framing, Security, Scheduling
- Handover/Mobility

Standards
- 802.16d and e (Ref interface R1)

WiMAX Forum

End-end Networking
- Reference architecture

Signaling, Network Mobility
-Messaging

Standards
- Ref interfaces R2-R8

Equipment Certification
- Europe and Asia

WiMAX is a Data Service

WiMAX Defined

- Differentiated Wireless Access Technology which provides
  - high Data Rates, that are
  - allotted flexibly, with
  - built in QoS and Security, supported through
  - complex scheduling algorithms, at a
  - relatively lower cost.

WiMAX uses Orthogonal Frequency Division Multiple Access (OFDMA)

A WIMAX system consists of:

- **A WiMAX tower**, similar in concept to a cell-phone tower - A single WiMAX tower can provide coverage to a very large area as big as 8,000 square km.
- **A WiMAX receiver** - The receiver and antenna could be a small box or Personal Computer Memory card, or they could be built into a laptop the way WiFi access is today

MODES OF OPERATION

- Non-Line of sight

  Uses a lower frequency range.

- Line of sight

  Uses a higher frequency range.

WIMAX Scenario

- Consider a scenario where a WiMax-enabled computer is 20 km away from the WiMax base station.

- A special encryption code is given to computer to gain access to base station

- The base station would beam data from the Internet required for computer (at speeds potentially higher than today's cable modems)

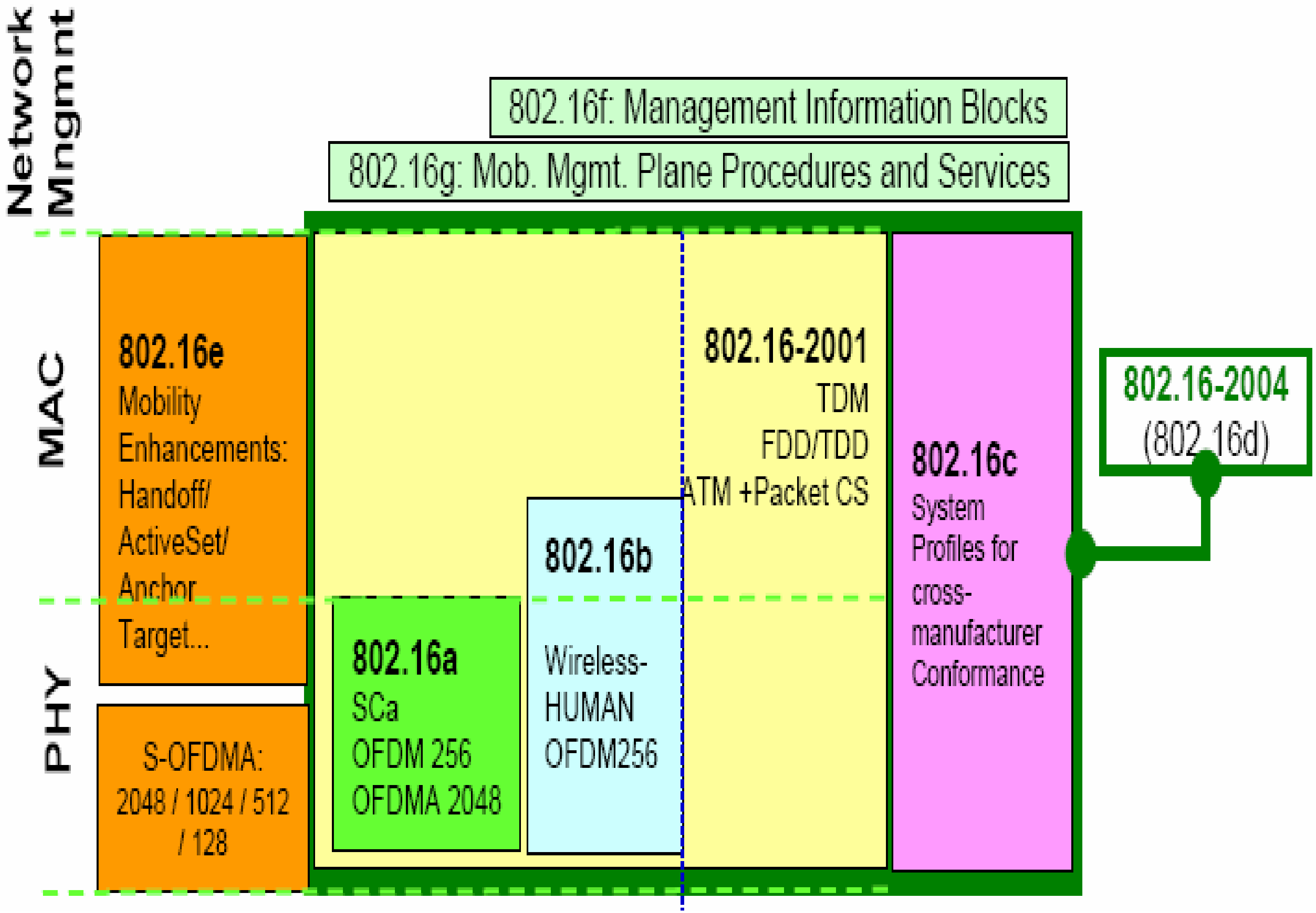
WIMAX Scenario

- The user would pay the provider monthly fee for using the service.
- The cost for this service could be much lower than current high-speed Internet-subscription fees because the provider never had to run cables
- The WiMAX protocol is designed to accommodate several different methods of data transmission, one of which is Voice Over Internet Protocol (VoIP)
- If WiMAX-compatible computers become very common, the use of VoIP could increase dramatically.
- Almost anyone with a laptop could make VoIP calls

IEEE 802.16

- Range- 50 km from base station
- Speed- 70 Megabits per second
- Frequency bands- 2 to 11 and 10 to 66(licensed and unlicensed bands respectively)
- Defines both MAC and PHY layer and allows multiple PHY layer specifications

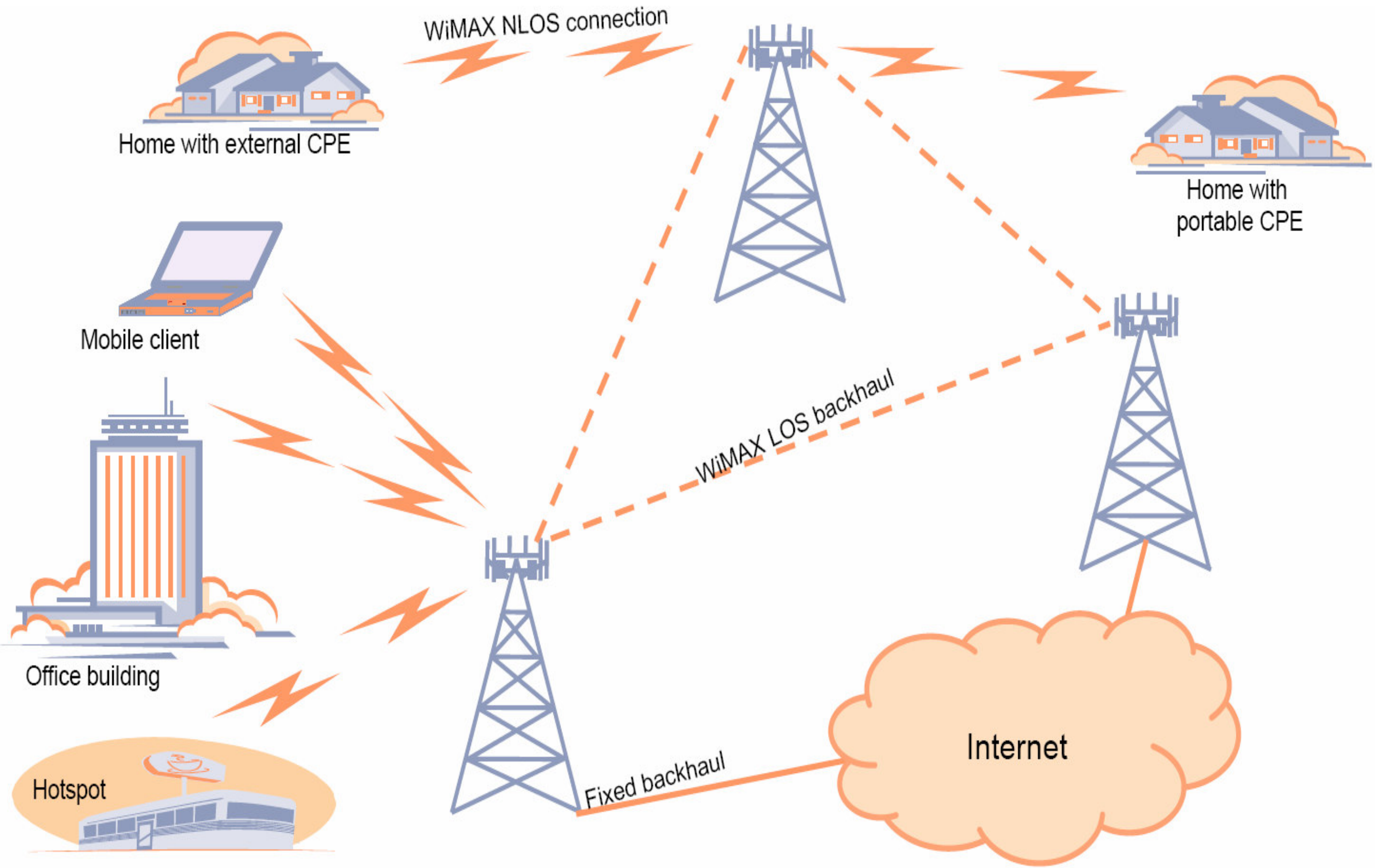
802.16 SPECIFICATIONS



IEEE 802.16 Specifications

- **802.16a**
  - Uses the licensed frequencies from 2 to 11 GHz
  - Supports Mesh network
- **802.16b**
  - Increase spectrum to 5 and 6 GHz
  - Provides QoS(for real time voice and video service)
- **802.16c**
  - Represents a 10 to 66GHz
- **802.16d**
  - Improvement and fixes for 802.16a
- **802.16e**
  - Addresses on Mobile
  - Enable high-speed signal handoffs necessary for communications with users moving at vehicular speeds

WiMax is well suited to offer both fixed and mobile access



How WiMax Works

- WiMax can provide 2 forms of wireless service:

  - Non-LOS, Wi-Fi sort of service, where a small antenna on a computer connects to the tower. Uses lower frequency range (2 to 11 GHz).

  - LOS, where a fixed antenna points straight at the WiMax tower from a rooftop or pole. The LOS connection is stronger and more stable, so it is able to send a lot of data with fewer errors. Uses higher frequencies, with ranges reaching a possible 66 GHz.

- Through stronger LOS antennas, WiMax transmitting stations would send data to WiMax enabled computers or routers set up within 50 km radius.

WiMax Applications

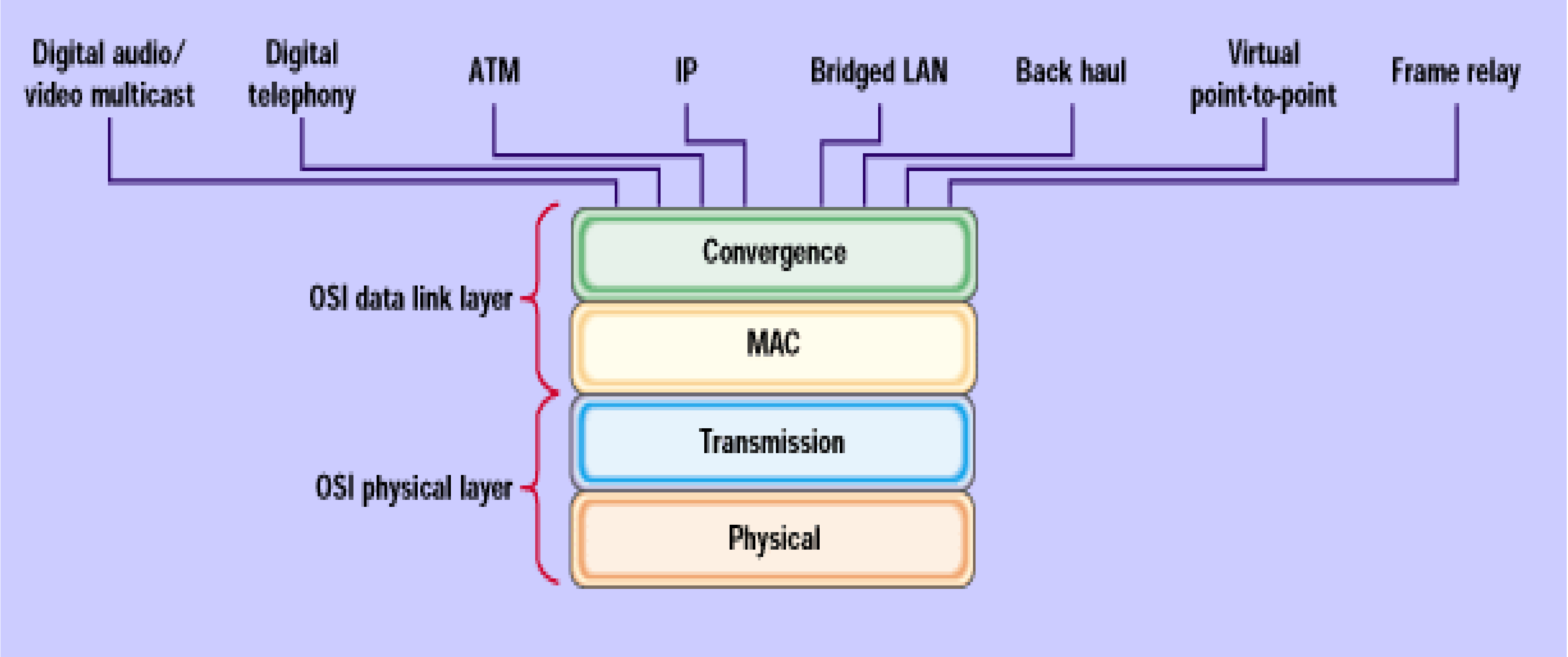
According to WiMax Forum it supports 5 classes of applications:

1. Multi-player Interactive Gaming.
2. VOIP and Video Conference
3. Streaming Media
4. Web Browsing and Instant Messaging
5. Media Content Downloads

802.16 Architecture

- IEEE 802.16 Protocol Architecture has 4 layers: Convergence, MAC, Transmission and physical, which can be mapped to two OSI lowest layers: physical and data

  link.



802.16 Architecture

- P2MP Architecture

  BS connected to Public Networks

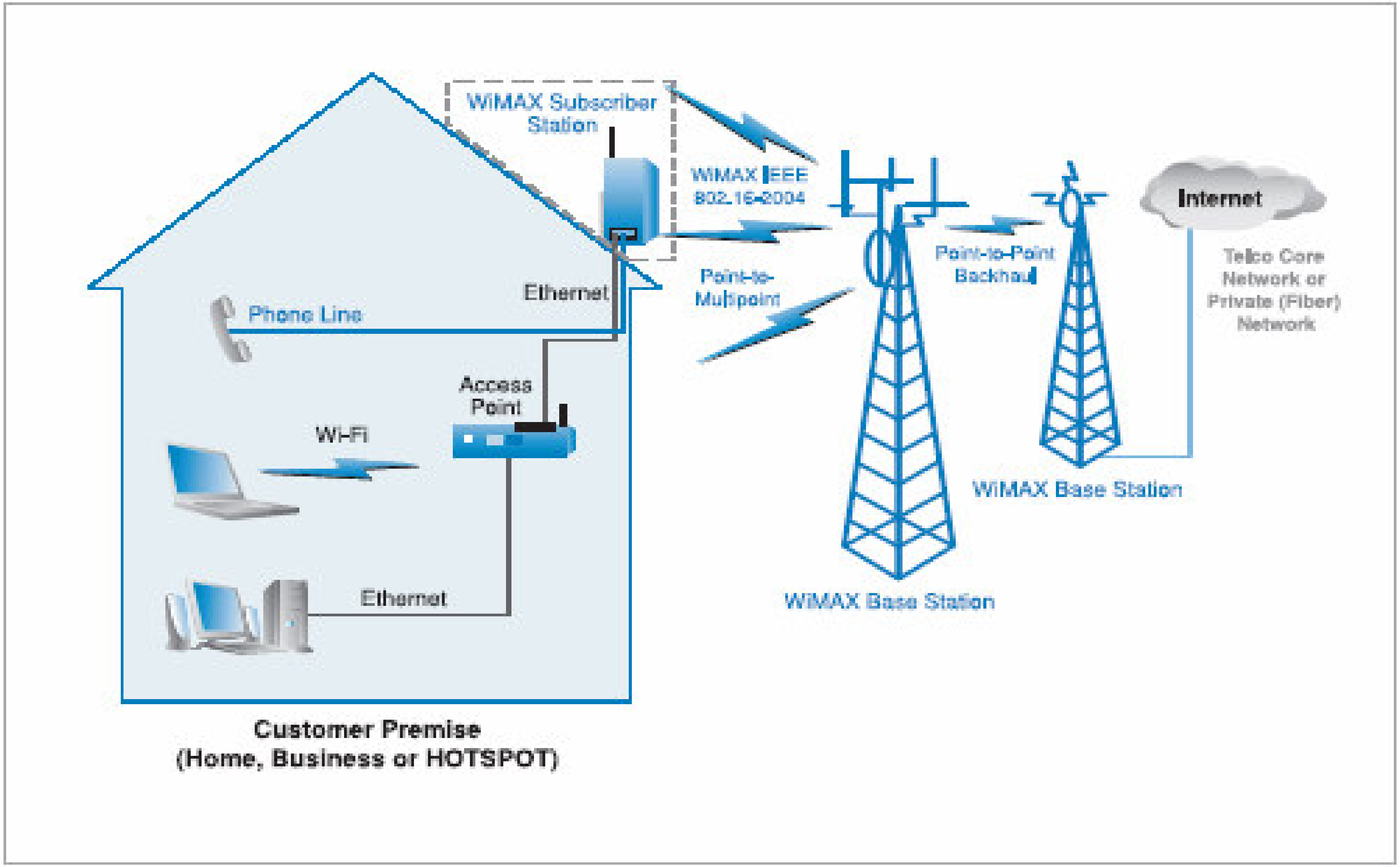
  BS serves Subscriber Stations (SS)

  Provides SS with first mile access to Public Networks

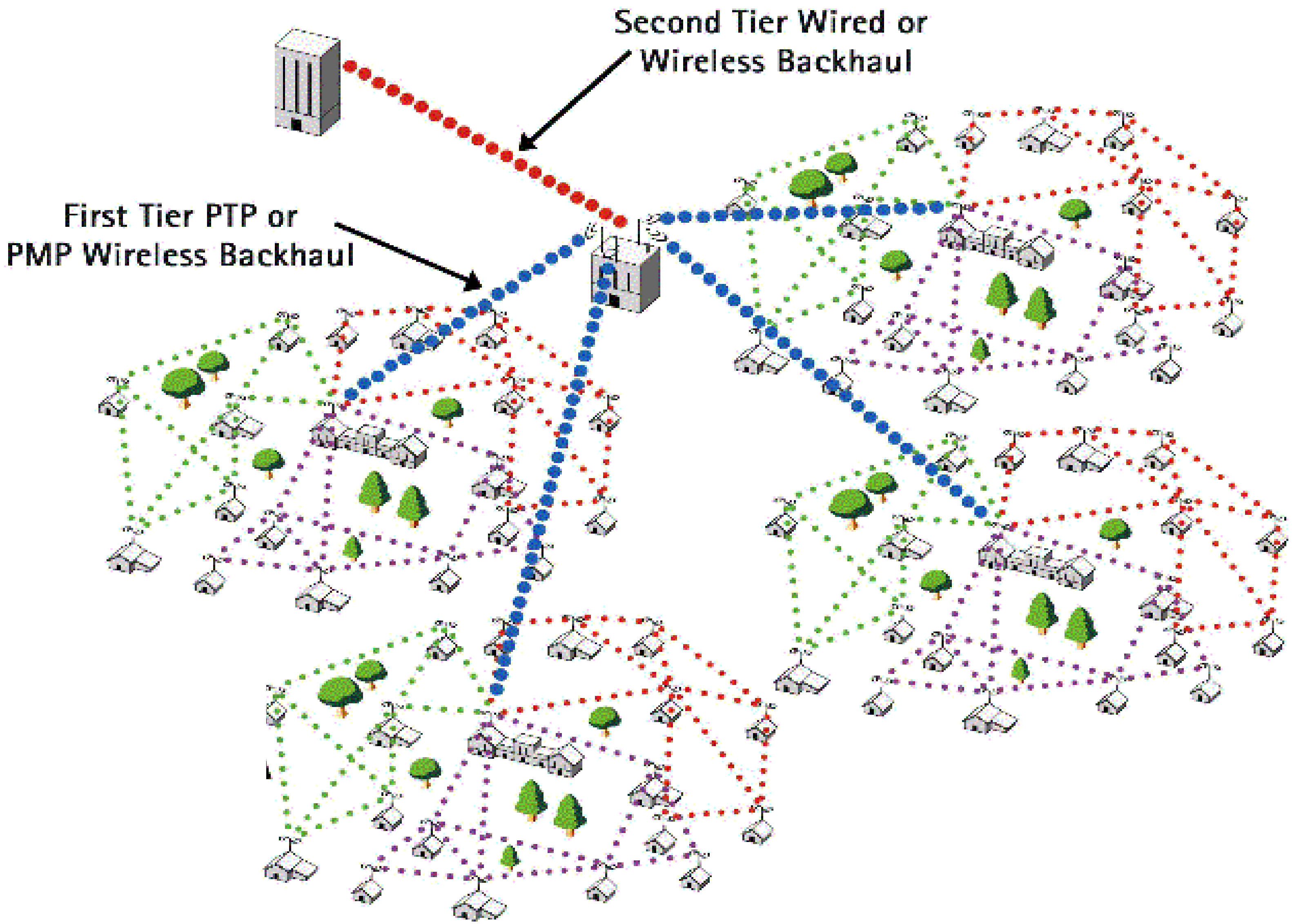
- Mesh Architecture

  Optional architecture for WiMAX

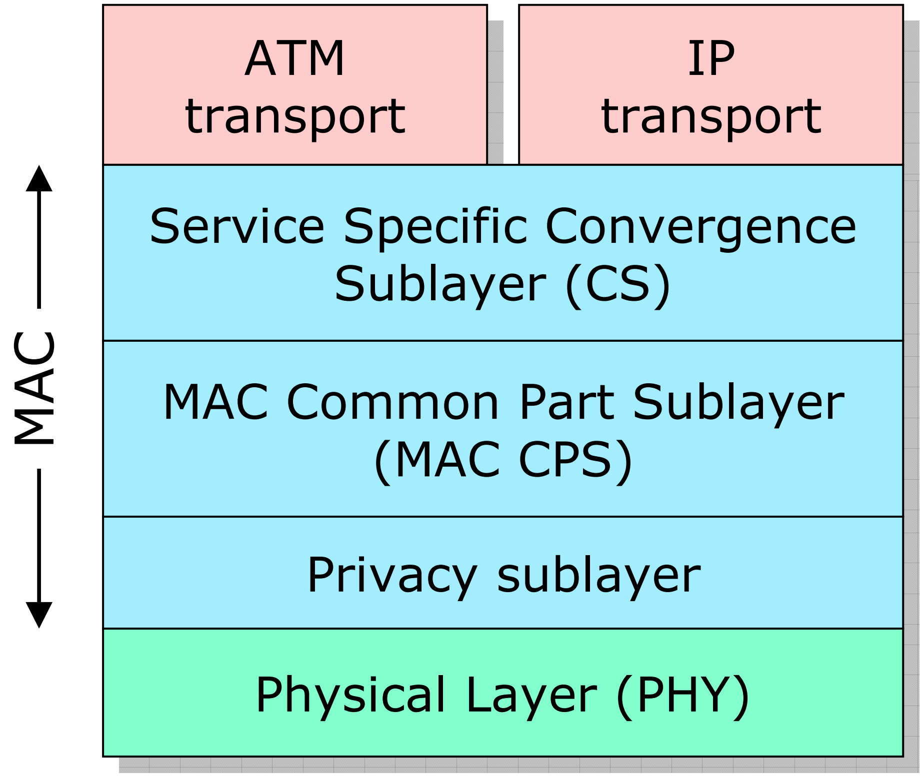
P2MP Architecture



Mesh Architecture



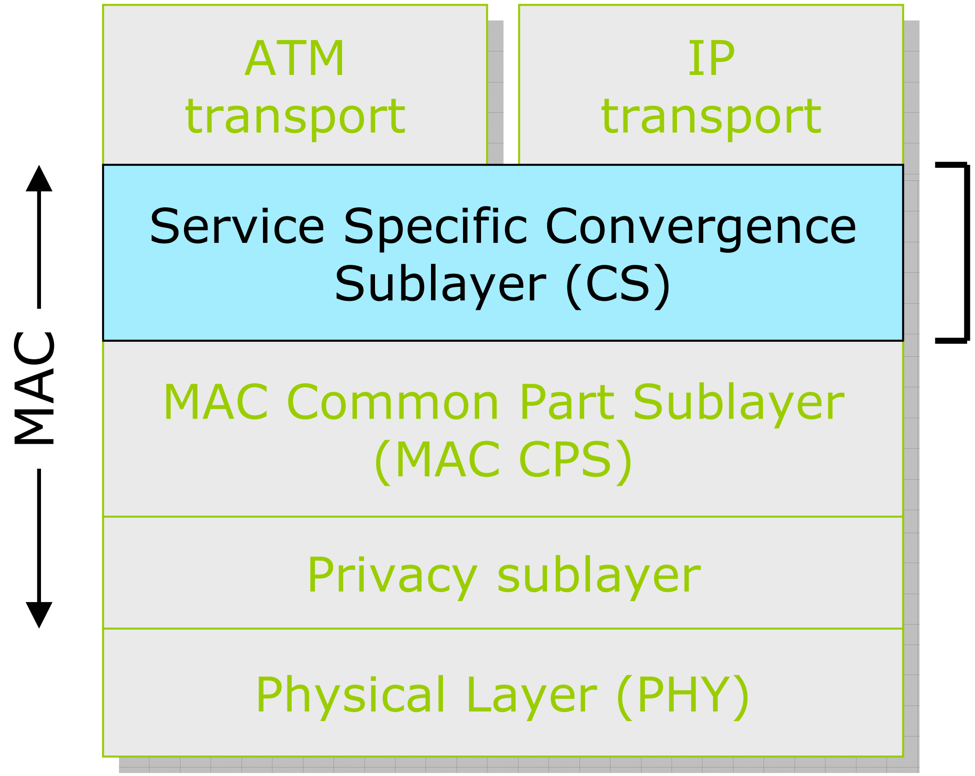
IEEE 802.16 protocol layering



Like IEEE 802.11, IEEE 802.16 specifies the Medium Access Control (MAC) and PHY layers of the wireless transmission system.

The IEEE 802.16 MAC layer consists of three sublayers.

IEEE 802.16 protocol layering

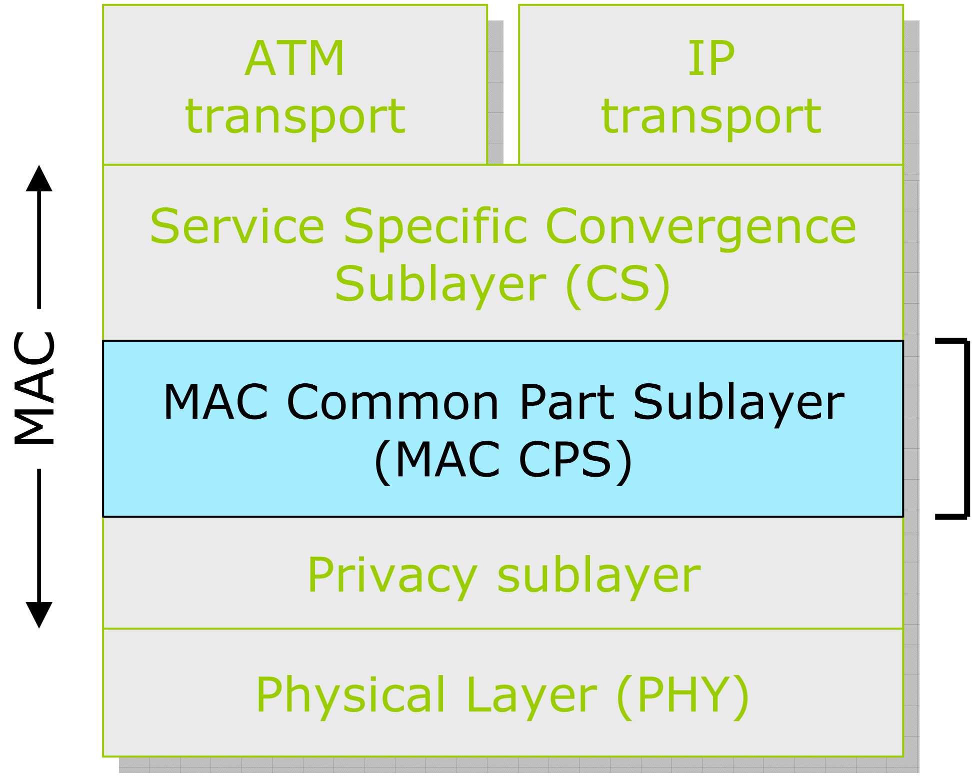


CS adapts higher layer protocols to MAC CPS.

CS maps data (ATM cells or IP packets) to a certain unidirectional connection identified by the Connection Identifier (CID) and associated with a certain QoS.

May also offer payload header suppression.

IEEE 802.16 protocol layering

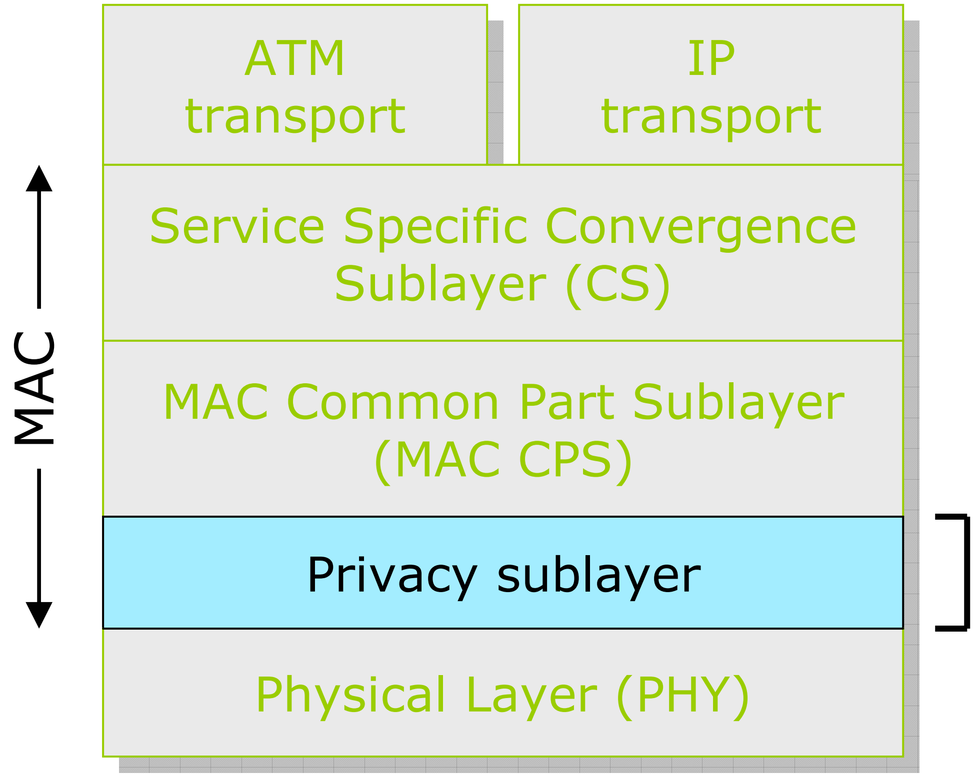


MAC CPS provides the core MAC functionality:

- System access
- Bandwidth allocation
- Connection control

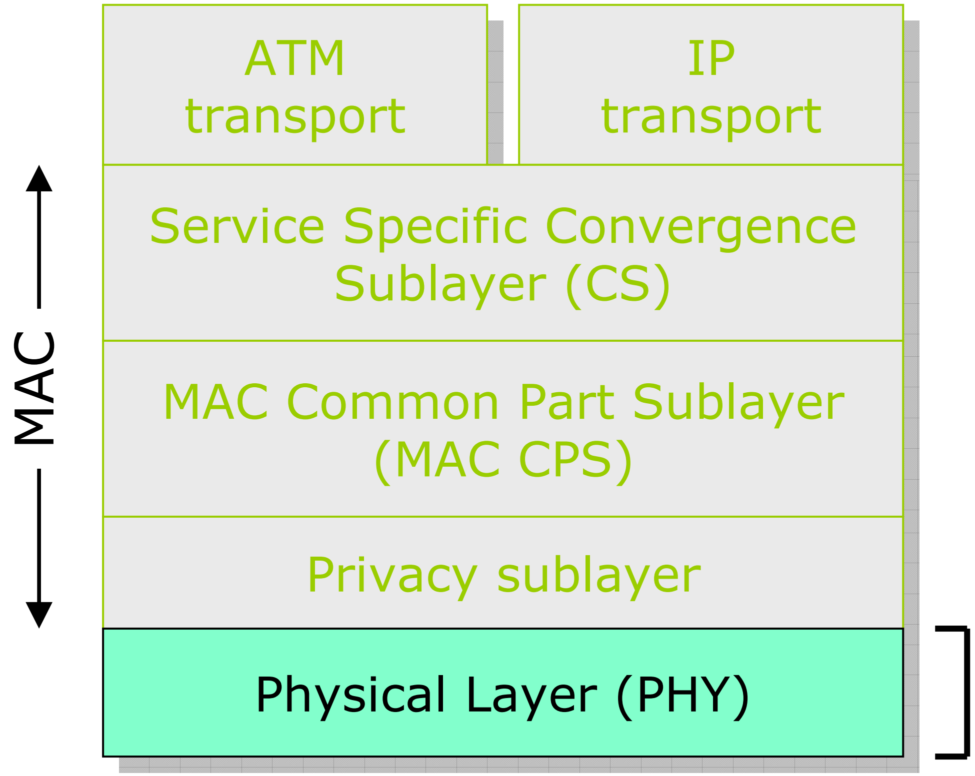
Note: QoS control is applied dynamically to every connection individually.

IEEE 802.16 protocol layering



The privacy sublayer provides authentication, key management and encryption.

IEEE 802.16 protocol layering



IEEE 802.16 offers three PHY options for the 2-11 GHz band:

- WirelessMAN-SCa
- WirelessMAN-OFDM
- WirelessMAN-OFDMA

IEEE 802.16 PHY

IEEE 802.16-2004 specifies three PHY options for the 2-11 GHz band, all supporting both TDD and FDD:

- WirelessMAN-SCa (single carrier option), intended for a line-of-sight (LOS) radio environment where multipath propagation is not a problem
- WirelessMAN-OFDM with 256 subcarriers (mandatory for license-exempt bands) will be the most popular option in the near future
- WirelessMAN-OFDMA with 2048 subcarriers separates users in the uplink in frequency domain (complex technology).

FEATURES OF WIMAX

- Scalability
- Quality of Service
- Range
- Coverage

Scalability

- The 802.16 standard supports flexible radio frequency (RF) channel bandwidths.

- The standard supports hundreds or even thousands of users within one RF channel

- As the number of subscribers grow the spectrum can be reallocated with process of sectoring.

Quality of Service

- Primary purpose of QoS feature is to define transmission ordering and scheduling on the air interface

- These features often need to work in conjunction with mechanisms beyond the air interface in order to provide end to end QoS or to police the behaviour or SS.

Requirements for QoS

- A configuration and registration function to pre configure SS based QoS service flows and traffic parameters
- A signalling function for dynamically establishing QoS enabled service flows and traffic parameters
- Utilization of MAC scheduling and QoS traffic parameters for uplink service flows
- Utilization of QoS traffic parameters for downlink service flows

RANGE

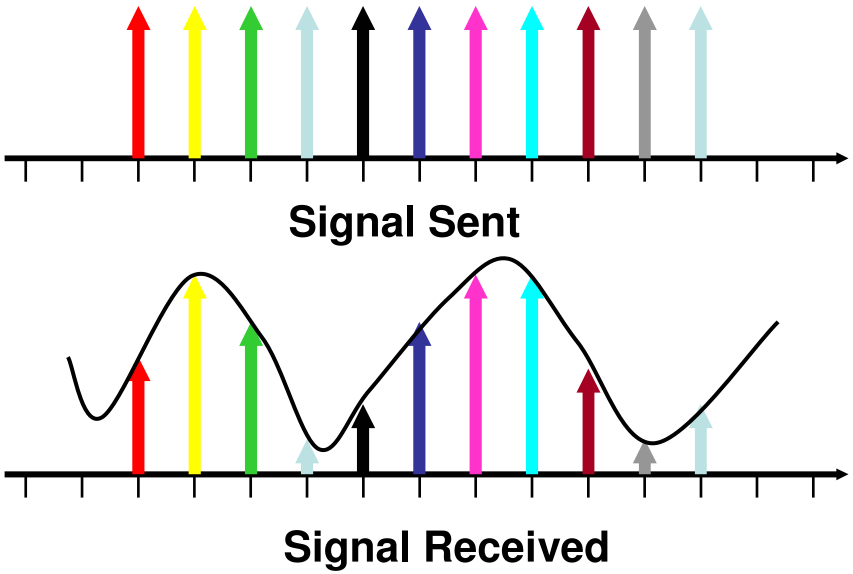
- Optimized for up to 50 Km
- Designed to handle many users spread out over kilometres
- Designed to tolerate greater multi-path delay spread (signal reflections) up to 10.0μ seconds
- PHY and MAC designed with multi-mile range in mind

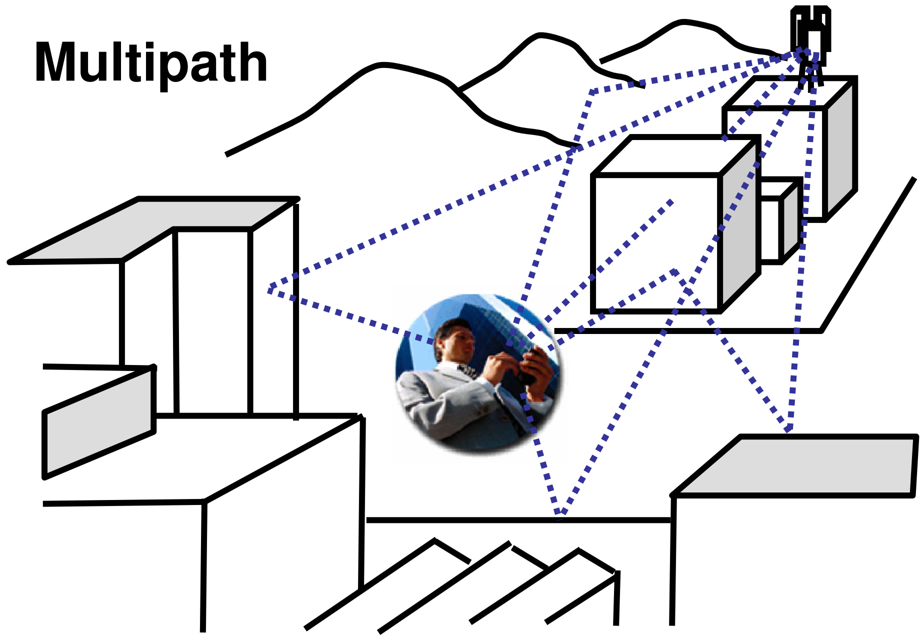
Coverage

- Standard supports mesh network topology
- Optimized for outdoor NLOS performance
- Standard supports advanced antenna techniques

Advantages in Multipath

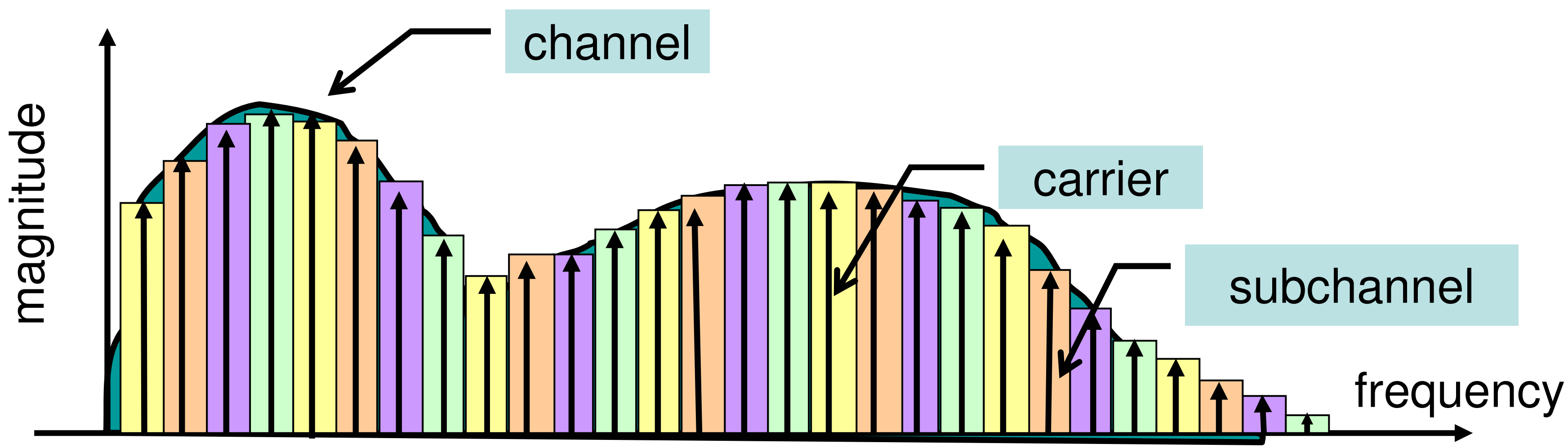
- **OFDMA carries advantages in "Multipath"**
  - **CDMA uses the whole spectrum, wasting system resource to combat frequency selective fading.**
  - **CDMA also creates worse interference problem**
  - **OFDMA only select subcarriers with less channel degradation, prevent wasting system resource (power or throughput) => achieving higher system capacity.**





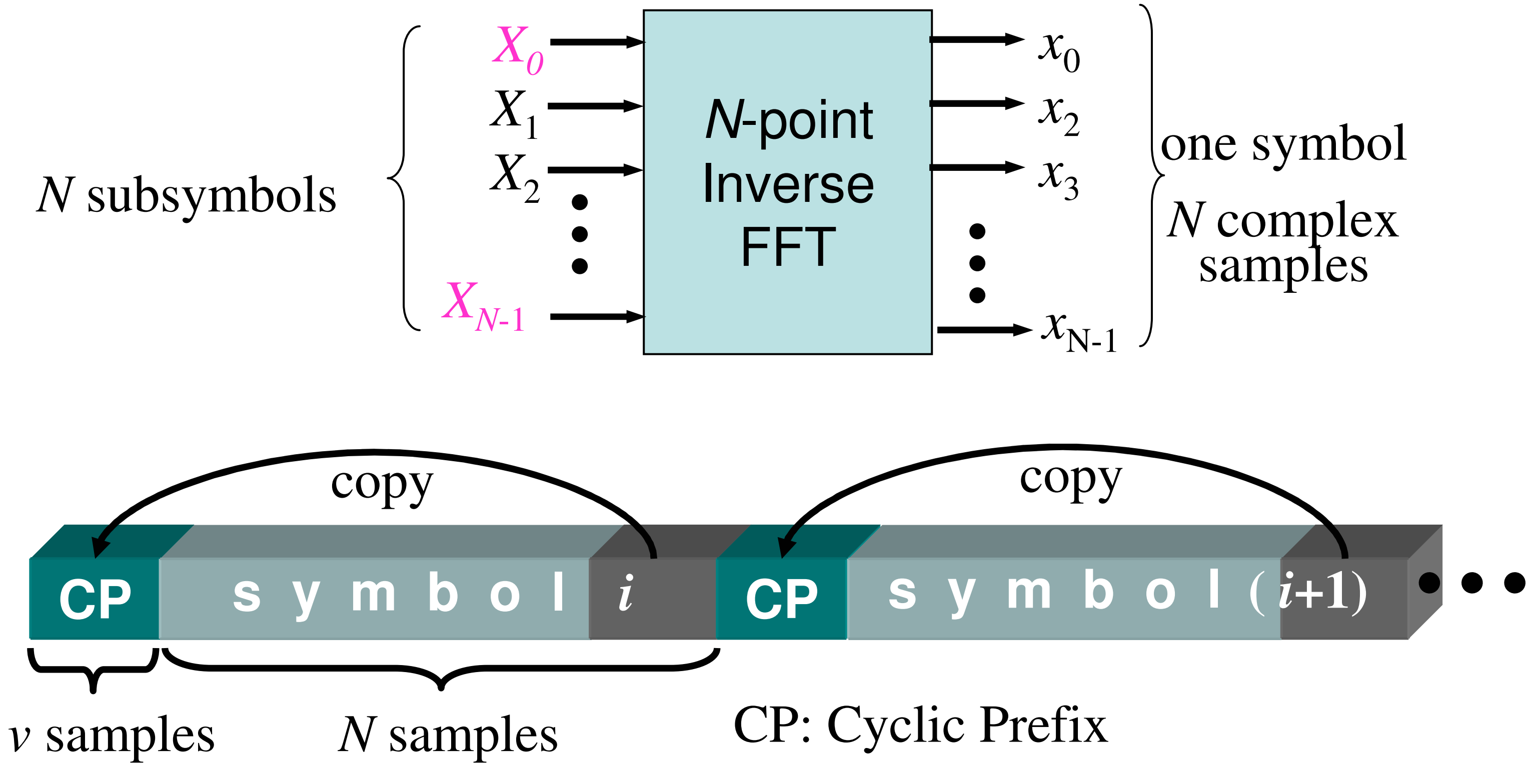
Multicarrier Modulation

- **Divide broadband channel into narrowband subchannels**
  - No ISI in *subchannels* if constant gain in every subchannel and if ideal sampling
- **Orthogonal Frequency Division Multiplexing**
  - Based on the fast Fourier transform
  - Standardized for DAB, DVB-T, IEEE 802.11a, 802.16a, HyperLAN II
  - Considered for fourth-generation mobile communication systems

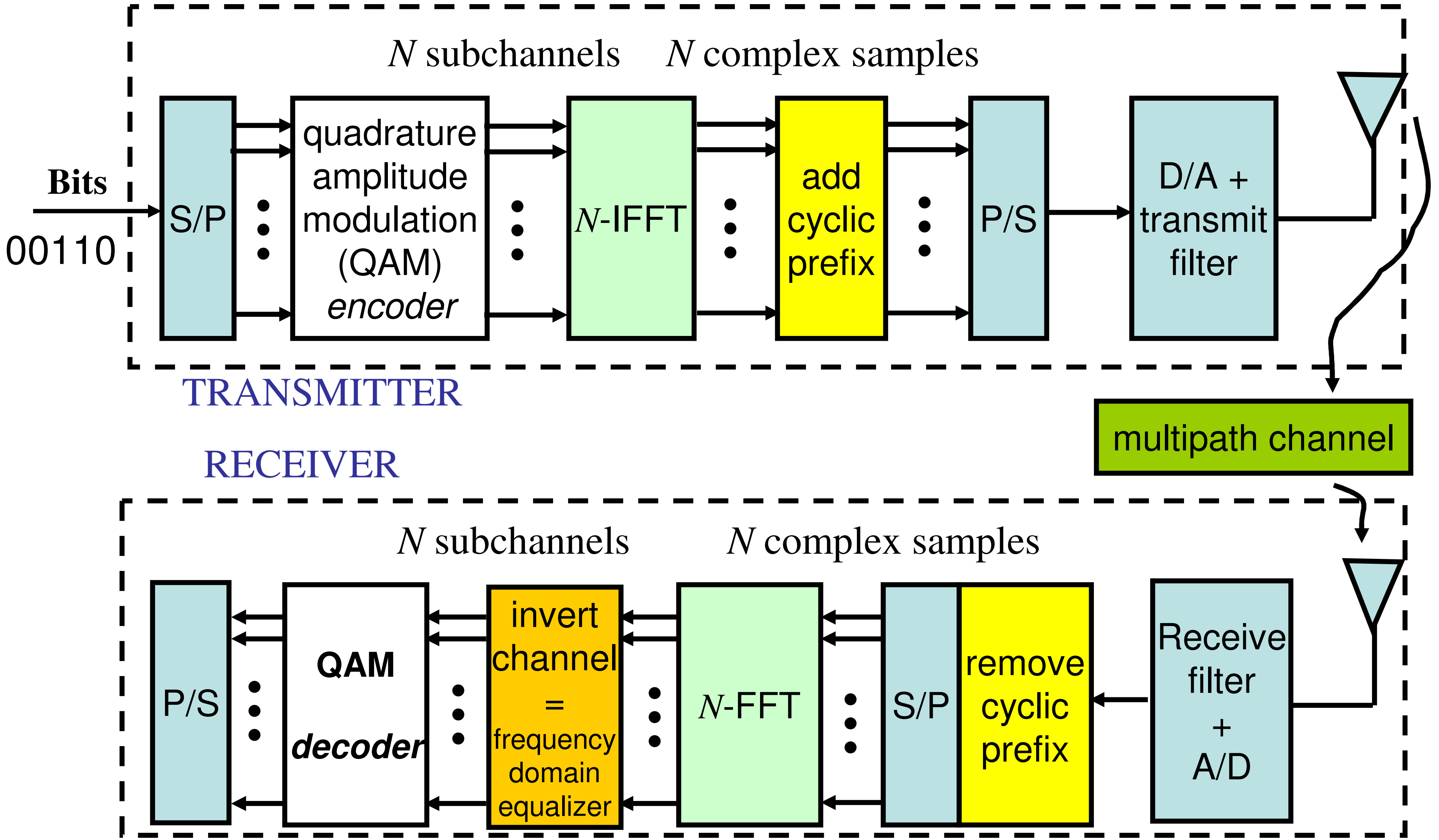


Subchannels are 312 kHz wide in 802.11a and HyperLAN II

An OFDM Symbol

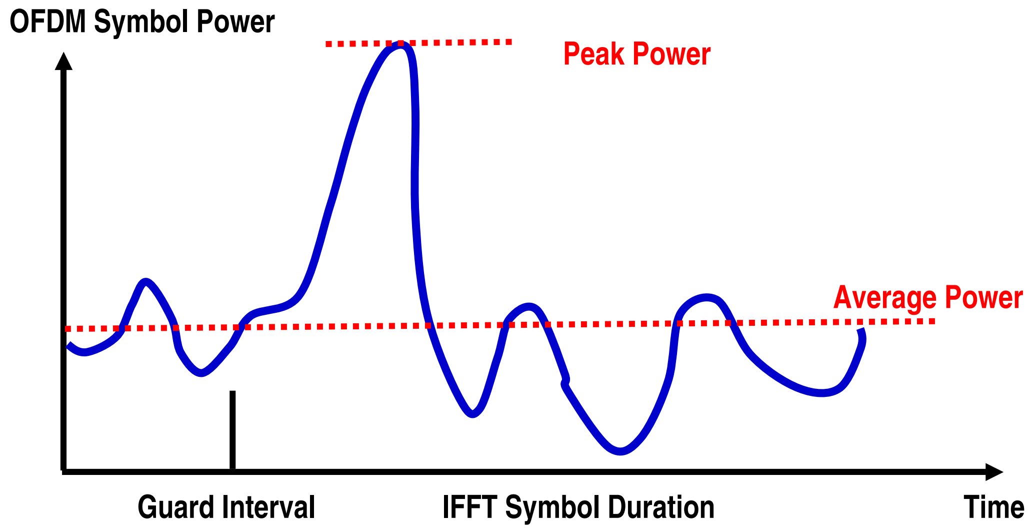


An OFDM Modem



Power and RF Constraint

- Battery Life Challenge
  - WiMAX standard was targeted to long range (high power), fixed (non-battery based), or portability (recharged daily), not mobility.
  - Higher data rate demands higher power transmission; battery technology show difficulty to catch up with the such demand.
  - Power consumption of WiMAX device could be a major problem.
- 802.16's Effort in Power/RF
  - Power-Saving mode and Scalable OFDMA are added to 802.16e
  - But higher FFT has more severe PAPR (peak to average power ratio)
  - Challenge the RF design for WiMAX



Use of WiMAX in urban and suburban areas

- To cover ADSL residual market (to achieve 100% broadband coverage)
- Hotspots turning into hot zones
- Backhaul of traffic, including cellular (replacement for leased lines)
- Deployed when fast response time is needed

Use of WiMAX in rural areas (1)

- WiMAX is a competitor for DSL in rural areas, especially in areas without xDSL or cable TV

- In case of an incumbent, WiMAX is also a complementary technology for DSL

- LOS connection often possible, allowing more robust link and higher throughput

Use of WiMAX in rural areas (2)

- WiMAX QoS feature allows for low-latency applications like VoIP and Video (UGS: Unsolicited Grant Services); whereas data services are Best Effort
- This allows operators to offer services like streaming video, along with voice and high-speed data connections

Network Operator Roles in WiMAX

- Network Access Provider (NAP)
  - A business entity that provides radio access infrastructure to one or more Network Service Providers.
- Network Service Provider (NSP)
  - A business entity that provides IP connectivity and network services to subscribers compliant with the Service Level Agreement it establishes with sub-scribers.
  - To provide these services, an NSP establishes contractual agreements with one or more NAPs.

Network Operator Roles in WiMAX

– An NSP may also establish roaming agreements with other NSPs and contractual agreements with third-party application providers (e.g. ASPs) for providing IP services to subscribers.

- ASP (Application Service Provider)
  - Provides and manages applications on top of IP
  - Provides value added services, Layer 3+ (e.g. VoIP, corporate access, ...)

WiMax Spectrum

- Broad Operating Range
- WiMax Forum is focusing on 3 spectrum bands for global deployment:
- Unlicensed 5 GHz: Includes bands between 5.25 and 5.85 GHz. In the upper 5 GHz band (5.725 – 5.850 GHz) many countries allow higher power output (4 Watts) that makes it attractive for WiMax applications.

WiMax Spectrum

- Licensed 3.5 GHz: Bands between 3.4 and 3.6 GHz have been allocated for BWA in majority of countries.
- Licensed 2.5 GHz: The bands between 2.5 and 2.6 GHz have been allocated in the US, Mexico, Brazil and in some SEA countries. In US this spectrum is licensed for MDS and ITFS.

Licensed and License-Exempt Bands

- Both solutions are based on IEEE 802.16-2004 standard, which uses OFDM in the physical (PHY) layer.
- OFDM provides benefits such as increased SNR of subscriber stations and improved resiliency to multi-path interference.
- For creating bi-directional channels for uplink and downlink, licensed solutions use FDD while license exempt solutions use TDD.

FUTURE

- WiMax will be deployed in three stages
  - In the first phase WiMaX technology (based on IEEE 802.16-2004) provides fixed wireless connections
  - In the second phase WiMaX will be available as a cheap and self-installing Subscriber Terminal (ST), linked to PC and to antenna
  - The third phase enables portability, thus WiMAX (based on IEEE 802.16e) will be integrated into commercial laptops

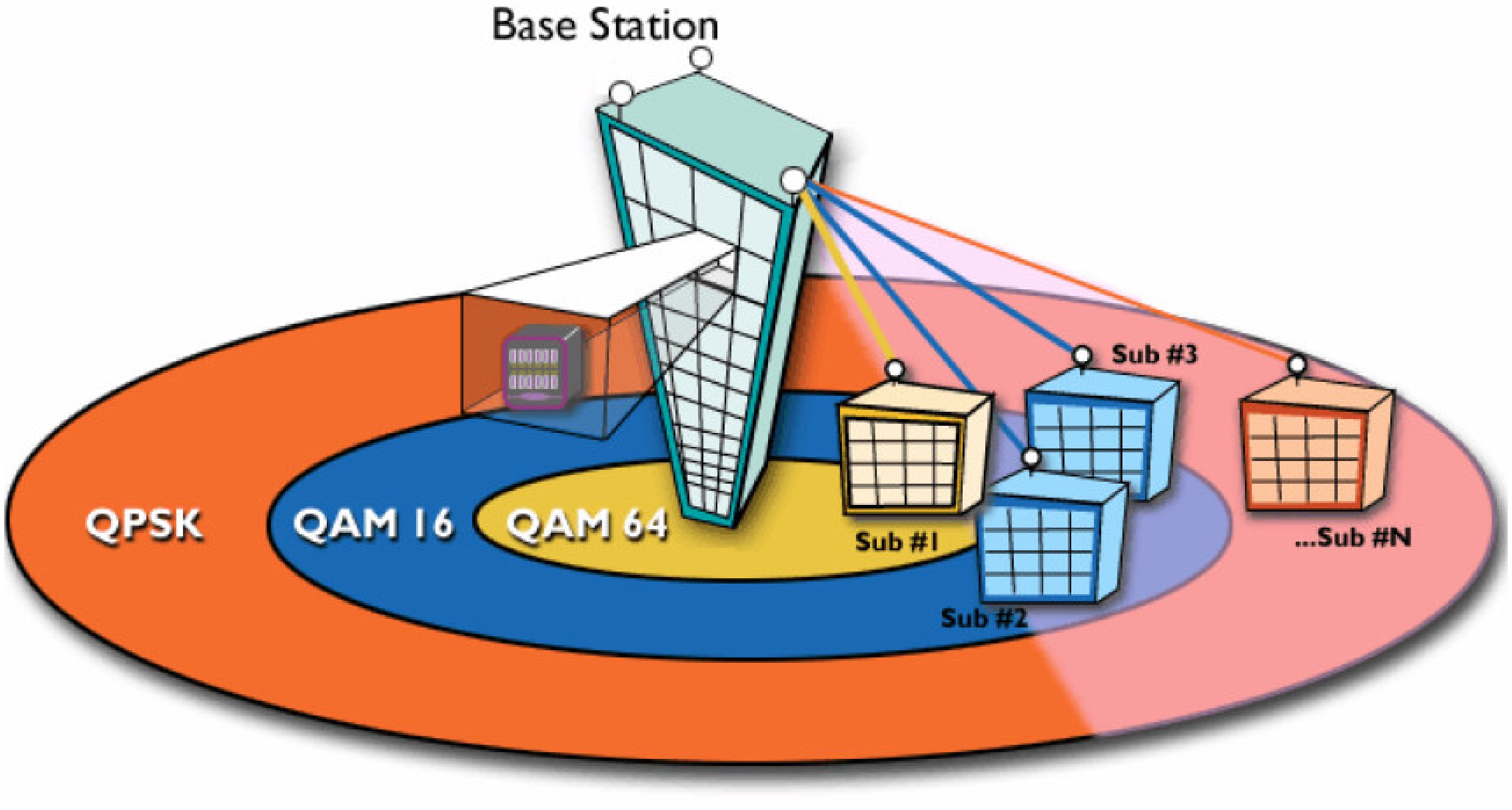
Communication Systems
WiMAX – wireless services

- Line-of-sight
  - A fixed dish antenna points straight at the WiMAX tower from a rooftop or pole.
  - 11 GHz to 66 GHz frequency range
  - At higher frequencies - there is less interference and lots more bandwidth
  - The connection is stronger and more stable, so it is able to send a lot of data with fewer errors.
- Non-line-of-sight
  - A small antenna on your computer connects to the WiMAX tower
  - 2 GHz to 11 GHz frequency range
  - At lower frequencies – longer wavelength transmissions are not as easily disrupted by physical obstructions – they are better able to diffract, or bend, around obstacles

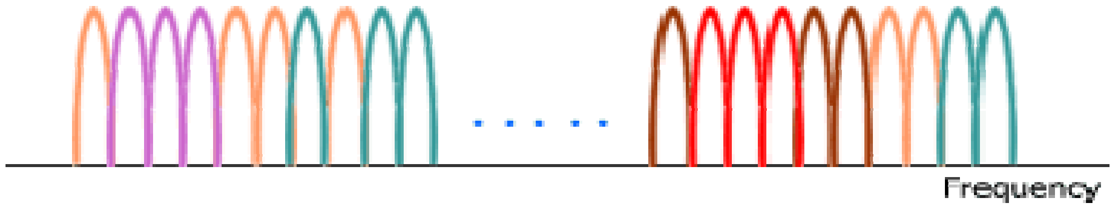
Communication Systems
Comparison of WiMAX and Wi-Fi

	WiMax (802.16a)	Wi-Fi (802.11b)	Wi-Fi (802.11a/g)
Primary Application	Broadband Wireless Access	Wireless LAN	Wireless LAN
Frequency Band	Licensed/Unlicensed 2 G to 11 GHz	2.4 GHz ISM	2.4 GHz ISM (g) 5 GHz U-NII (a)
Channel Bandwidth	Adjustable 1.25 M to 20 MHz	25 MHz	20 MHz
Half/Full Duplex	Full	Half	Half
Radio Technology	OFDM (256-channels)	Direct Sequence Spread Spectrum	OFDM (64-channels)
Bandwidth Efficiency	≤5 bps/Hz	≤0.44 bps/Hz	≤2.7 bps/Hz
Modulation	BPSK, QPSK, 16-, 64-, 256-QAM	QPSK	BPSK, QPSK, 16-, 64-QAM
FEC	Convolutional Code Reed-Solomon	None	Convolutional Code
Encryption	Mandatory- 3DES Optional- AES	Optional- RC4 (AES in 802.11i)	Optional- RC4 (AES in 802.11i)
Access Protocol	Request/Grant	CSMA/CA	CSMA/CA
- Best Effot	Yes	Yes	Yes
- Data Priority	Yes	802.11e WME	802.11e WME
- Consistent Delay	Yes	802.11e WSM	802.11e WSM
Mobility	Mobile WiMax (802.16e)	In development	In development
Mesh	Yes	Vendor Proprietary	Vendor Proprietary

Adaptive PHY



Orthogonal Frequency Division Multiple Access (OFDMA) (4/5)



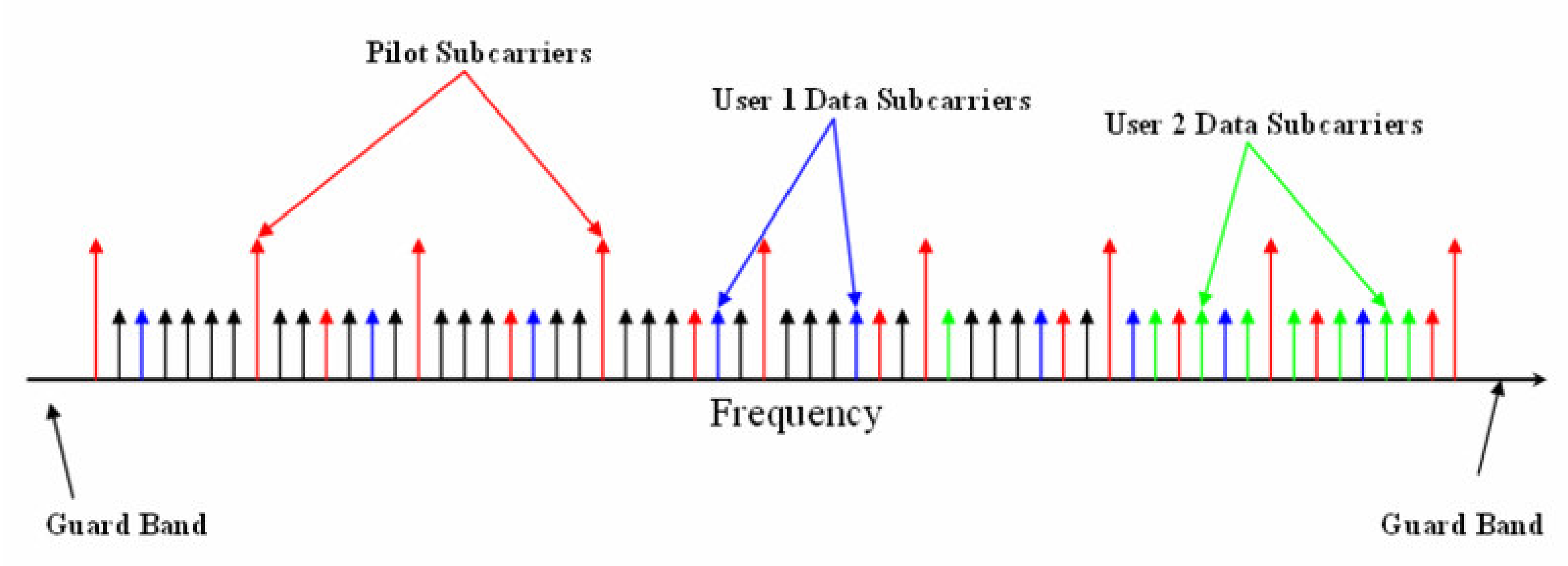
- Like OFDM, OFDMA employs multiple closely spaced sub-carriers, but the sub-carriers are divided into groups of sub-carriers.

- Each group is named a sub-channel. The sub-carriers that form a sub-channel need not be adjacent.

- In the downlink, a sub-channel may be intended for different receivers. In the uplink, a transmitter may be assigned one or more sub-channels.

- Subchannelization defines sub-channels that can be allocated to subscriber stations (SSs) depending on their channel conditions and data requirements.

Orthogonal Frequency Division Multiple Access (5/5)



- (**OFDMA**) is a multi-user version of the popular OFDM digital modulation scheme.
- Multiple access is achieved in OFDMA by assigning subsets of sub-carriers to individual users as shown in the figure.
- This allows simultaneous low data rate transmission from several users.

SOFDMA (S-OFDMA) (1/3)

- As a reminder, IFFT (Inverse Fast Fourier Transform) is used in a WiMAX transmitter to create an OFDM waveform from modulated data streams, while FFT (Fast Fourier Transform) is used in a WiMAX receiver to demodulate the data streams.

- The FFT size equals the number of sub-carriers, e.g. in a OFDM/OFDMA system with 256 sub-carriers, the FFT size is 256.

SOFDMA (S-OFDMA) (2/3)

- Adds scalability to OFDMA. It scales the FFT size to the channel bandwidth while keeping the sub-carrier frequency spacing constant across different channel bandwidths.
- Smaller FFT size is given to lower bandwidth channels, while larger FFT size to wider channels.
- By making the sub-carrier frequency spacing constant, SOFDMA reduces system complexity of smaller channels and improves performance of wider channels.

SOFDMA (S-OFDMA) (3/3)

- SOFDMA is the OFDMA mode used in Mobile WiMAX.
- It supports channel bandwidths ranging from 1.25 MHz to 20 MHz.
- With bandwidth scalability, Mobile WiMAX technology can comply with various frequency regulations worldwide and flexibly address diverse operator or ISP requirements, that's whether for providing only basic Internet service or a broadband service bundle.

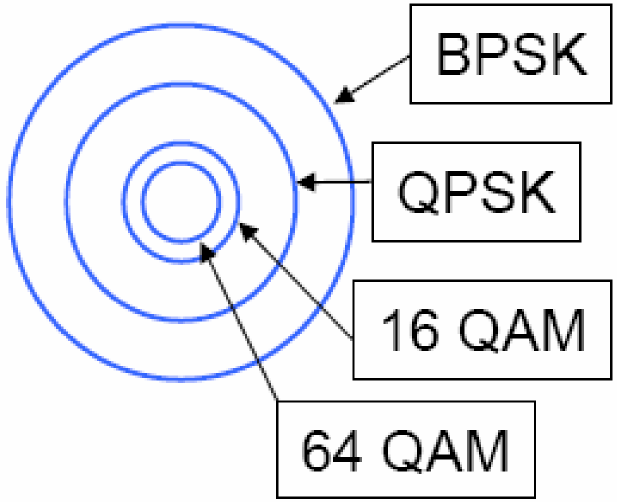
IEEE 802.16e – (S)OFDMA

Same advantage as OFDM, but also includes:

- Supports simultaneous transmission from several SSs
  - OFDMA is the ‘multi-user’ version of OFDM
  - Assigns subsets of sub-carriers depending on bandwidth needed by SS (later)
- Fixed devices reach same speed as OFDM256, whereas mobile devices trade off mobility (max 125km/h) against bandwidth

IEEE 802.16e – (S)OFDMA

- Downlink sub-channelization allows adaptive modulation scheme depending on distance of user (trade-off coverage versus capacity)
- Larger FFT sizes
  - the signal can cope against larger delay spreads
  - More resistant to multipath fading (occurs with NLOS transmission)
  - FFT size dynamically changeable in SOFDMA



IEEE 802.16e – (S)OFDMA

– Flexible (scalable) sub-carrier bandwidths between 1.25MHz and 20 MHz
  - WLAN (OFDM) has fixed sub-carrier bandwidth

Not used is SOFDMA

Parameters	Values				
System bandwidth (MHz)	1.25	2.5	5	10	20
Sampling frequency (F_s, MHz)	1.429	2.857	5.714	11.429	22.857
Sample time ($1/F_s$, nsec)	700	350	175	88	44
FFT size (N_{FFT})	128	256	512	1024	2048
Subcarrier frequency spacing	11.16071429 kHz				

WiBro

Practically unusable (~2 symbols; high overhead)

OFDM PHY: Raw Bit Rate (Mbps)

Modulation / Code Rate	QPSK 3/4	16 QAM 1/2	16 QAM 3/4	64 QAM 2/3	64 QAM 3/4
1.75MHz	2.18	2.91	4.36	5.94	6.55
3.5MHz	4.37	5.82	8.73	11.88	13.09
7.0 MHz	8.73	11.64	17.45	23.75	26.18
10.0MHz	12.47	16.63	24.94	33.25	37.40
20.0MHz	24.94	33.25	49.87	66.49	74.81

Modulation and coding combinations

Modulation	Coding rate	Info bits / subcarrier	Info bits / symbol	Peak data rate (Mbit/s)
BPSK	1/2	0.5	88	1.89
QPSK	1/2	1	184	3.95
QPSK	3/4	1.5	280	6.00
16-QAM	1/2	2	376	8.06
16-QAM	3/4	3	568	12.18
64-QAM	2/3	4	760	16.30
64-QAM	3/4	4.5	856	18.36

Depends on chosen bandwidth (here 5 MHz is assumed)

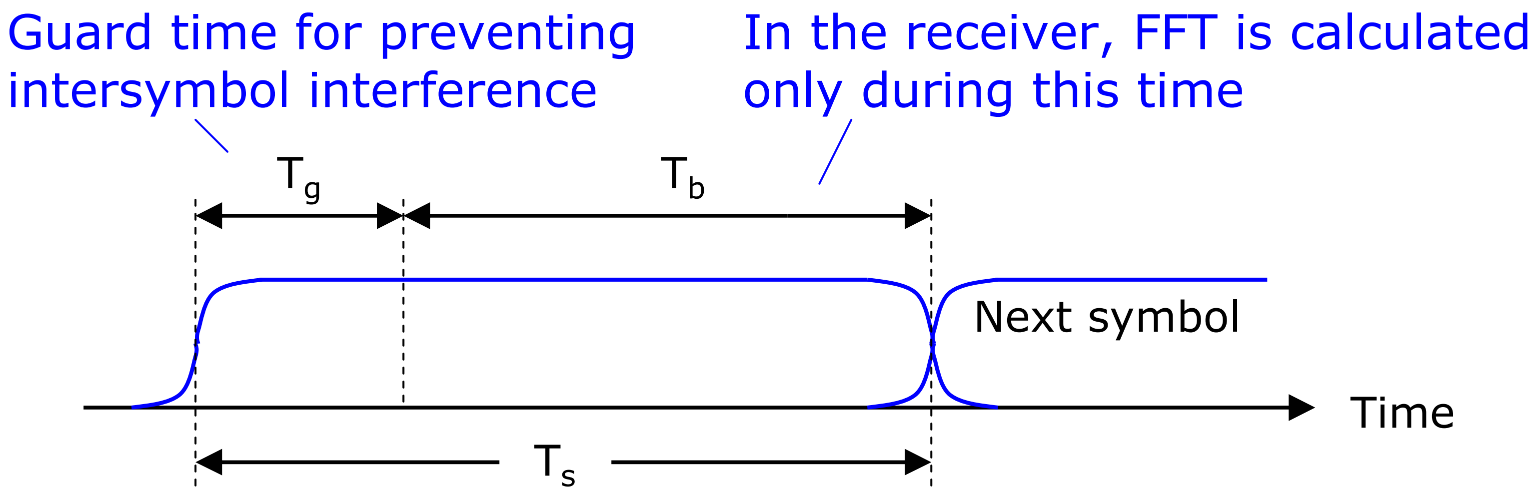
Modulation and coding affect user data rate

The 192 data subcarriers carry 192 data symbols in parallel (= transmitted at the same time). Each symbol carries 1 bit (BPSK), 2 bits (QPSK), 4 bits (16-QAM), or 6 bits (64-QAM) of channel information (corresponding to the channel bit rate after channel coding, not to be confused with the user bit rate before channel coding).

The inner convolutional coding reduces the usable number of bits to 1/2, 2/3, or 3/4 of the channel information.

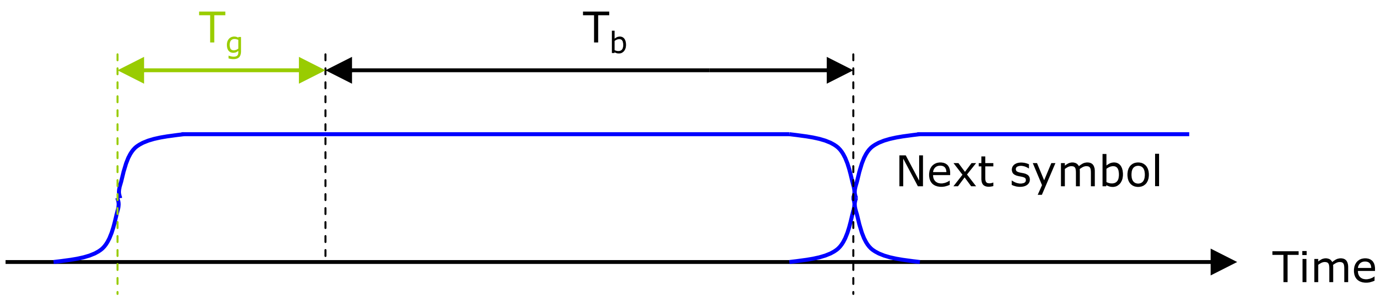
The outer Reed-Solomon block coding furthermore reduces the usable number of bits about 10 %.

Subcarrier signal in time domain (1)



IEEE 802.16 offers four values for $G = T_g/T_b$: G = 1/4, 1/8, 1/16 or 1/32. (802.11a/g offers only one value: G = 1/4)

Subcarrier signal in time domain (2)



IEEE 802.16 offers various bandwidth choices. The bandwidth is typically an integer multiple of 1.25, 1.5 or 1.75 MHz.
(802.11a/g offers only a fixed channel bandwidth: 16.25 MHz)

Since the number of subcarriers is fixed, a certain bandwidth is translated into a certain subcarrier spacing $\Delta f = 1/T_b$.

Four primitive parameters

WirelessMAN-OFDM defines four "primitive parameters" that characterize the OFDM symbol:

- The nominal channel bandwidth BW
- The number of used subcarriers N_{used} = 200
- The sampling factor n. This parameter depends on the bandwidth. For instance, when the bandwith is a multiple of 1.25, 1.5 or 1.75 MHz, n = 144/125, 86/75 or 8/7, respectively.
- The guard time to useful symbol time ratio G.

Derived parameters

Using the four primitive parameters shown on the previous slide, the following additional parameters can be derived:

N_{FFT} (the smallest power of two greater than N_{used}) = 256

Sampling frequency f_s = floor(n·BW/8000)x8000

Subcarrier spacing $\Delta f = f_s/N_{FFT}$

Useful symbol time $T_b = 1/\Delta f$

Guard time $T_g = G \cdot T_b$

OFDM symbol time $T_s = T_g + T_b$.

Example

For BW = 5 MHz, BPSK, G = 1/32, calculate peak bit rate:

f_s = floor(144/125 x 5 MHz / 8000) x 8000 = 5.76 MHz

$\Delta f = f_s/N_{FFT}$ = 5.76 MHz / 256 = 22.5 kHz

$T_b = 1/\Delta f$ = 44.44 μs

$T_g = G \cdot T_b$ = 1.39 μs

$T_s = T_g + T_b$ = 45.83 μs

Peak bit rate = (192 bits x 0.5 x 0.9) / 45.83 μs
= 1.89 Mb/s

86.4 info bits / OFDM symbol

Modulation and coding combinations

Modulation	Coding rate	Info bits / subcarrier	Info bits / symbol	Peak data rate (Mbit/s)
BPSK	1/2	0.5	88	1.89
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64-QAM	3/4	4.5	856	18.36

Depends on chosen bandwidth (here 5 MHz is assumed)

Example (cont.)

The peak bit rate does not take into account the MAC layer overhead (MAC PDU header and trailer) and PHY layer overhead (contention slots and burst preamble in UL, DL PHY PDU preamble and header in DL).

Consequently, the user data rate is substantially smaller (even if the SS is the only user of the WMAN).