4G Mobile Wireless WiMAX

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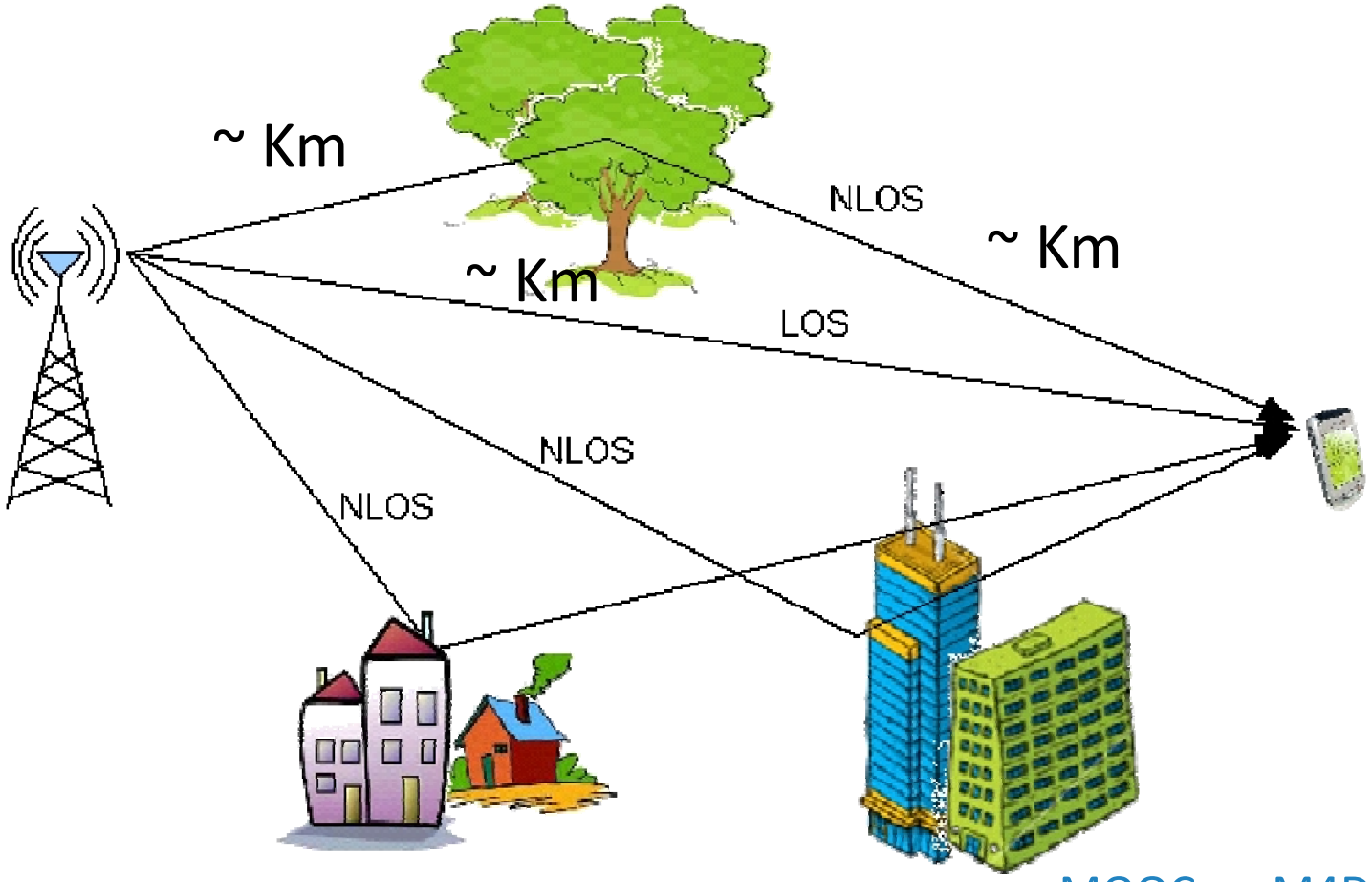
WSSUS Channel Variables - Delay

- Typical wireless channel delay spreads are of the order of 3 μs.



WSSUS Channel Variables - Delay

- Therefore, to avoid ISI, $T > T_d = 3\ \mu s$.
- It is immediately clear the maximum symbol rate in outdoor channels is,

$$R_{\max} = \frac{1}{3 \times 10^{-6}} = 333\,\text{Kbps}$$

Coherence bandwidth

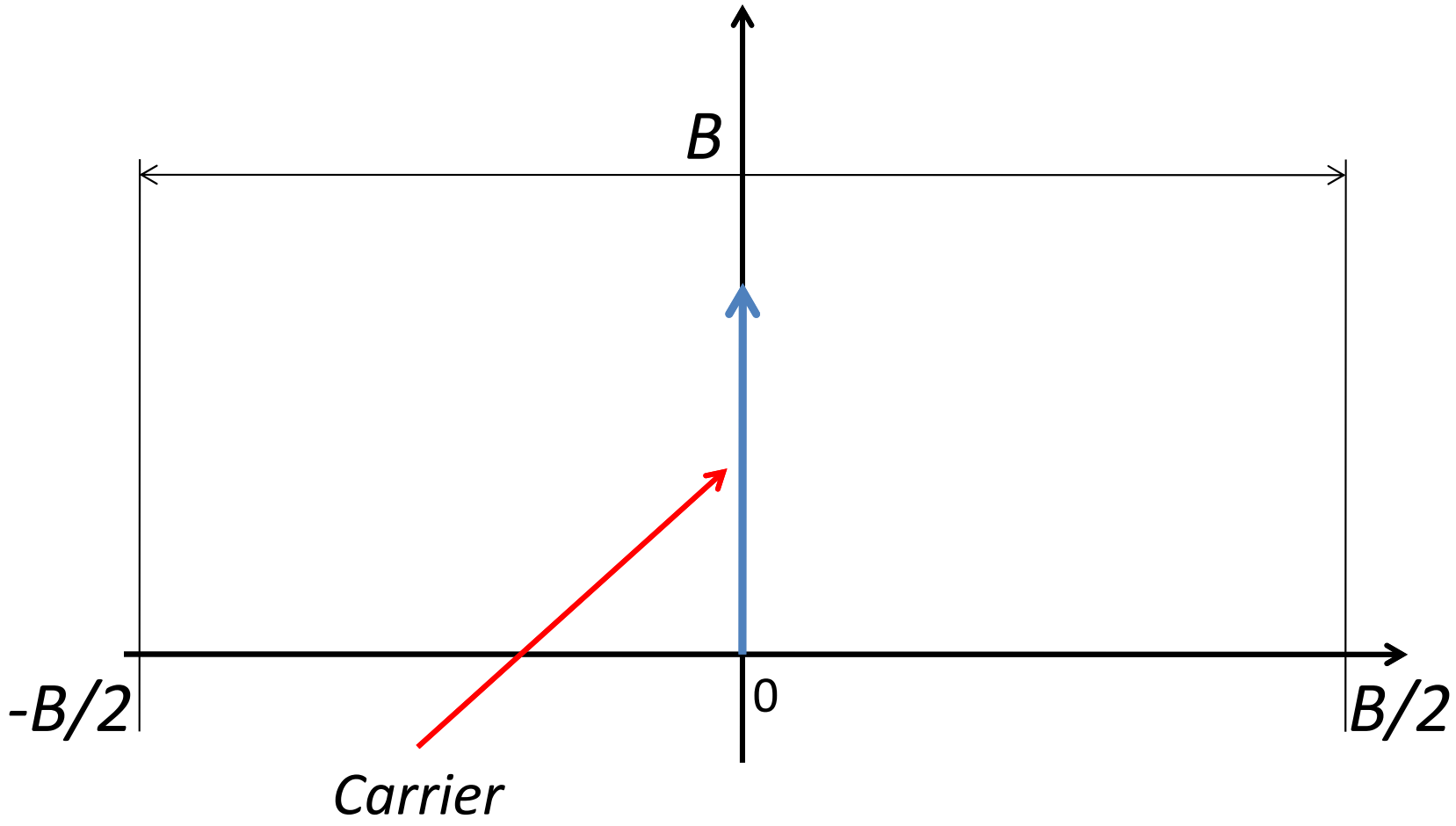
- Coherence bandwidth of the channel is defined in terms of delay spread as,

$$B_c \approx \frac{1}{T_d}$$

- For outdoor channels, $T_d \sim 3\ \mu s$ as seen earlier.
  - Hence, the coherence bandwidth B_c is given as,

$$B_c \approx \frac{1}{3\times 10^{-6}} = 333\,\mathrm{KHz}$$

Single Carrier Schematic



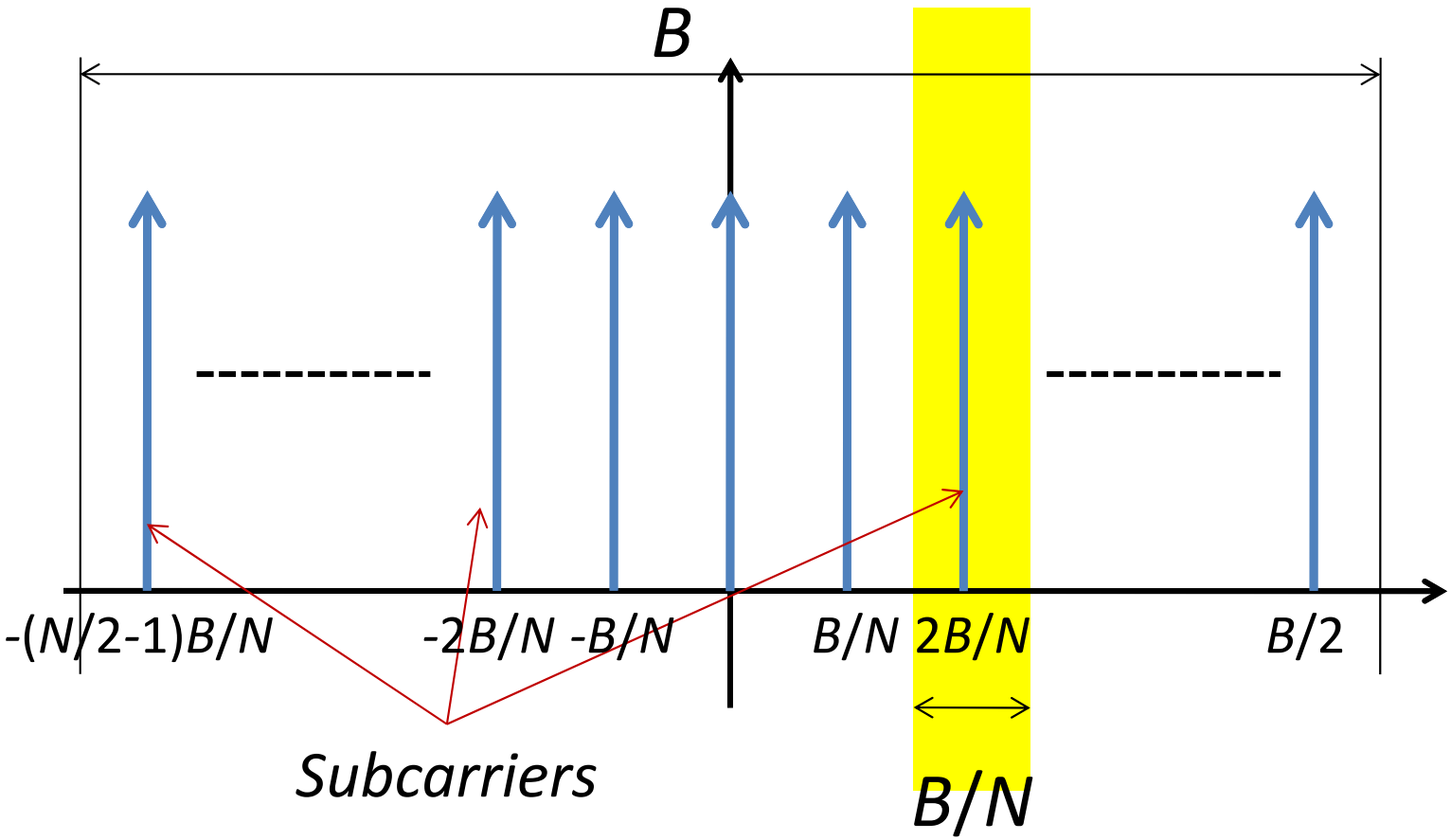
B = 10 – 20 MHz

Single Carrier Vs. Multi Carrier

- Consider instead a multi-carrier modulation (MCM) with N sub-bands of bandwidth B/N.

- Each band of bandwidth B/N has a subcarrier.

Multi Carrier Schematic



B = 10 MHz, N = 1000, B/N = 10 KHz

Multi-Carrier Communication

- The *N* subcarriers are at frequencies

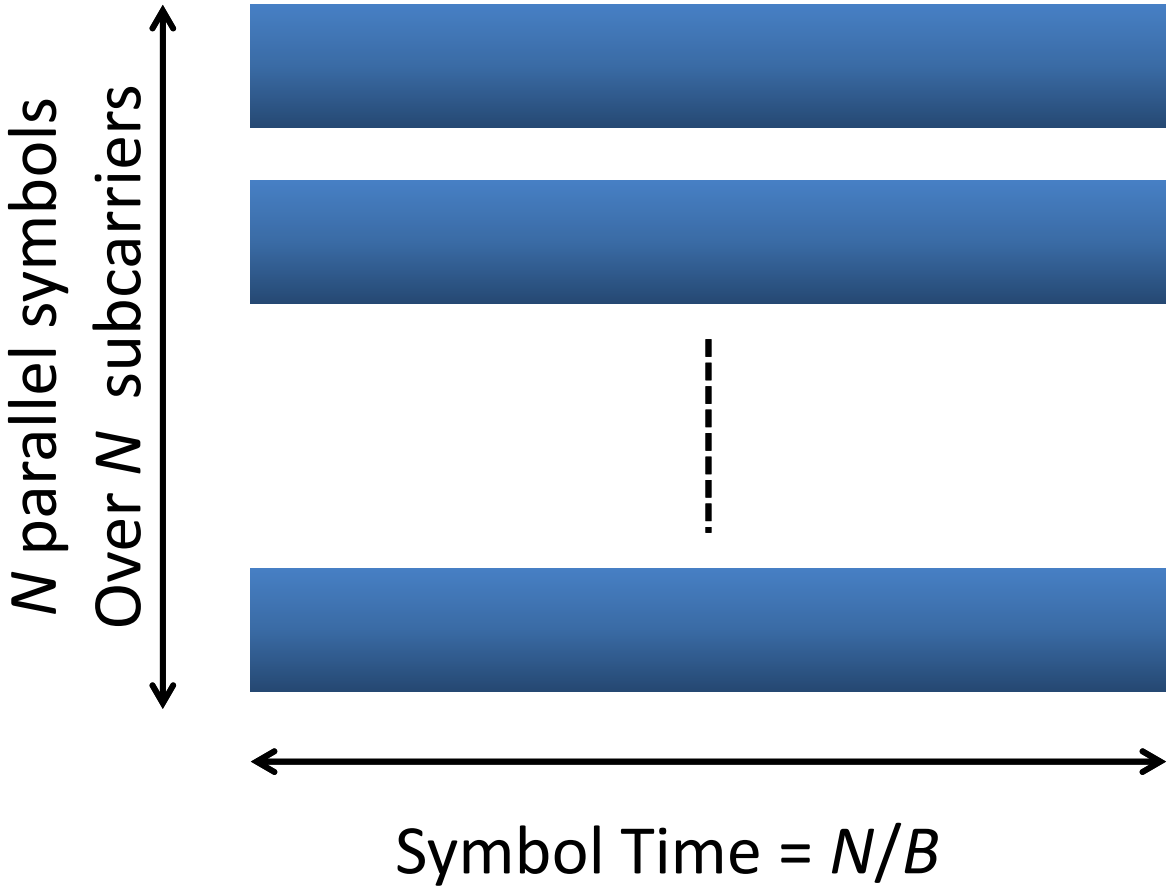
$$-\left(\frac{N}{2}-1\right)\frac{B}{N},-\left(\frac{N}{2}-2\right)\frac{B}{N},\cdots,-\frac{B}{N},0,\frac{B}{N},\cdots,\left(\frac{N}{2}\right)\frac{B}{N}$$

- The i^{th} SC is at if_o, where f_o = B/N is the ***fundamental frequency*** of the multi-carrier system.

$$f_i = if_o = i\frac{B}{N},\ -\left(\frac{N}{2}-1\right) \le i \le \left(\frac{N}{2}\right)$$

MCM – Overall Rate

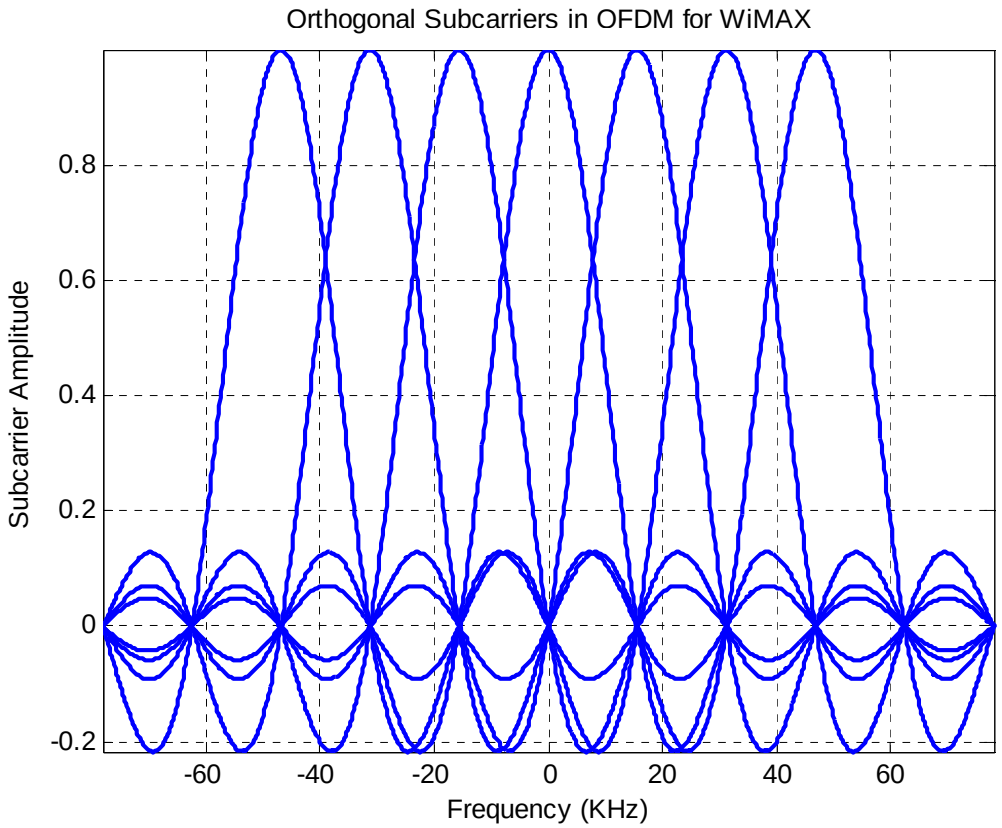
- In an MCM system, one is transmitting *N* parallel symbols over time *N*/*B*.



Orthogonal Frequency Division Multiplexing (OFDM)

- By converting a wideband channel into multiple **orthogonal** narrowband channels, one can tremendously simplify the receive processing.
  - If the subcarrier bandwidth is less than the coherent bandwidth, then each narrowband carrier experiences **flat-fading**.
- It can be processed with much lower complexity compared to *frequency-selective* fading.

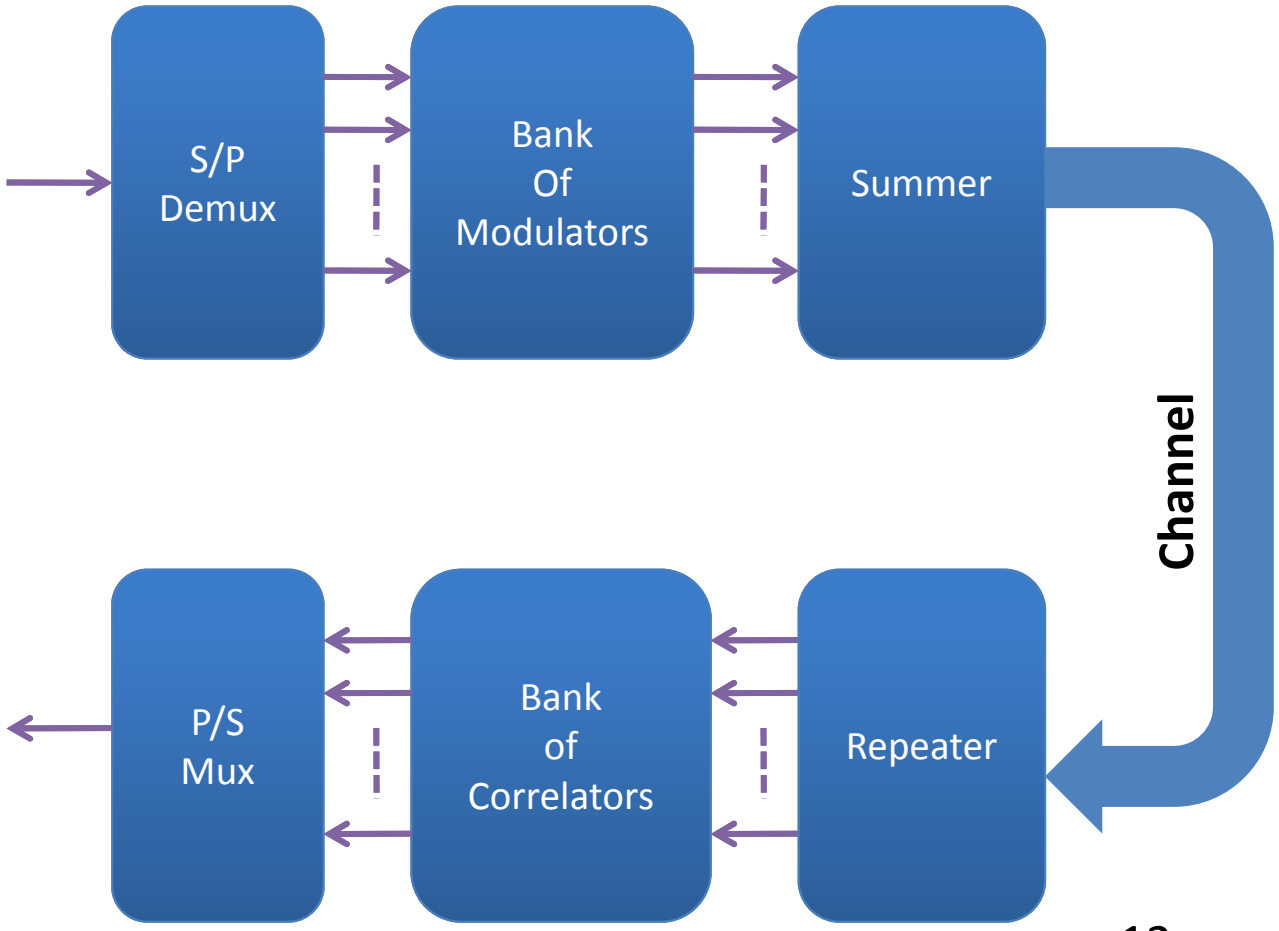
Orthogonal Frequency Division Multiplexing



- Orthogonal subcarriers in a WiMAX system with a carrier spacing of 15.625 KHz.
- Observer, there is NO *guard* band
  - Hence, efficient use of spectrum

Orthogonal Frequency Division Multiplexing

- An OFDM schematic employing a bank of modulators (BoM) is given below.



WiMAX
Worldwide Interoperability for microwave access

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WiMAX Timeline - Beginnings

- IEEE 802.16 group was formed in 1998
  - To develop an air-interface standard for wireless broadband.
- Initially focused at development of an LOS-based point-to-multipoint WBS.
  - Slated for operation in the 10GHz–66GHz millimeter wave band.

WiMAX Timeline - Beginnings

- The resulting standard—the original 802.16 was completed in December 2001.
- Salient features of this standard included
  - Single-carrier physical (PHY) layer.
  - Burst time division multiplexed (TDM) MAC layer.

WiMAX Timeline - Precursor

- The IEEE 802.16 group subsequently produced 802.16a, an amendment to the 802.16 standard.
  - Included NLOS applications in the 2GHz–11GHz band (Multipath Propagation).
  - Employed an O*rthogonal* F*requency* D*ivision* M*ultiplexing (OFDM) based physical layer.*
  - *Additions to the MAC (Medium Access Control) layer, such as support for Orthogonal* F*requency* D*ivision* M*ultiple* A*ccess (OFDMA), were also included.*

WiMAX Timeline - Precursor

- Further revisions resulted in a new standard in 2004, called IEEE 802.16-2004.
  - This formed the basis for the first WiMAX solution.

WiMAX Timeline - Inception

- Early solutions based on the IEEE 802.16-2004 targeted fixed applications.
  - Referred to as fixed WiMAX.
- In December 2005, the IEEE 802.16 group completed and approved IEEE 802.16e-2005.
  - Amended the earlier fixed WiMAX IEEE 802.16-2004 standard to add **mobility** support.
  - This forms the basis for the WiMAX solution for mobile applications.
  - Often referred to as **mobile WiMAX.**

PHY (Physical) Layer

- PHY is responsible for transmission and reception of radio signals
- The WiMAX physical layer (PHY) is based on Orthogonal Frequency Division Multiplexing.
  - This offers simplified reception in multipath and allows WiMAX to operate in NLOS conditions.
  - OFDM is now widely recognized as the PHY of choice for mitigating multipath in Broadband Wireless Access (BWA) – WLAN, LTE, Bluetooth

WiMAX OFDM Parameters

Parameter	Fixed WiMAX	Mobile WiMAX			
Number of Subcarriers	256	128	**512**	1024	2048
Used data subcarriers	192	72	**360**	720	1440
Pilot subcarriers	8	12	**60**	120	240
Number of null/guardband subcarriers	56	44	**92**	184	368
Cyclic Prefix	1/32, 1/16, 1/8, 1/4				
Oversampling Rate (Fs/BW)	Depends on BW. 7/6 for 256 OFDM, 8/7 for multiples of 1.75 MHz and 28/25 for multiples of 1.25 MHz, 1.5 MHz, 2 MHz or 2.75 MHz.				
Channel BW (MHz)	3.5	1.25	**5**	10	20
Subcarrier spacing	15.625	**10.94**			

WiMAX Features

- WiMAX Supports Several Advanced Features
  - Scalable Data rate and number of subcarriers (128 – 2048)
  - Adaptive Modulation and Coding (Number of bits per symbol and Error Control)
  - High Peak Data Rates ~ 75-100 Mbps
  - Advanced Antenna Techniques

WiMAX Features

Alamouti
Space-Time Code

Beamforming
Directional Transmission

Spatial Multiplexing
Transmission of Multiple Streams

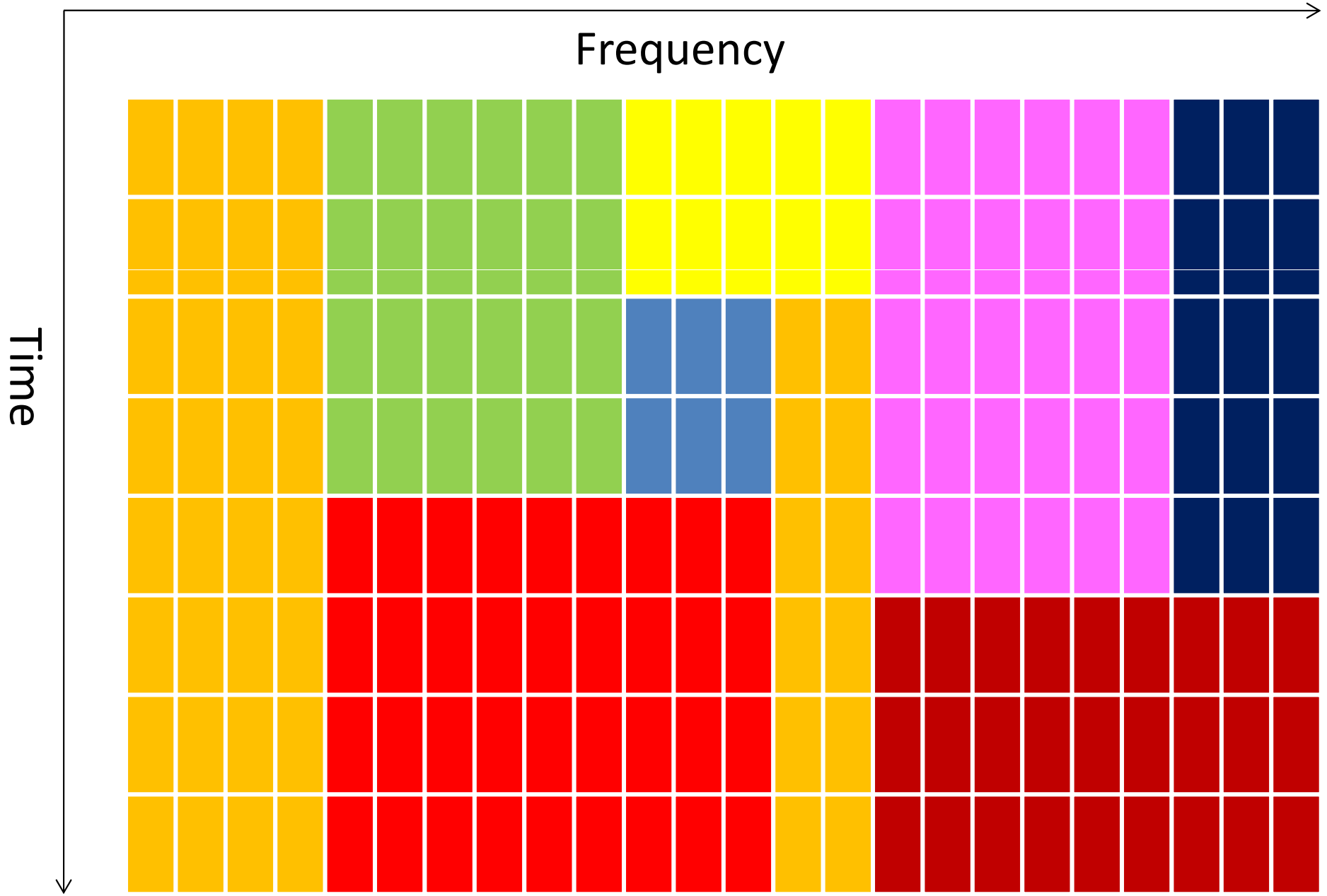
WiMAX Features

- Support for TDD and FDD
  - *Fixed*-WiMAX and *mobile*-WiMAX support both TDD and FDD.
  - This allows for a low-cost system implementation.

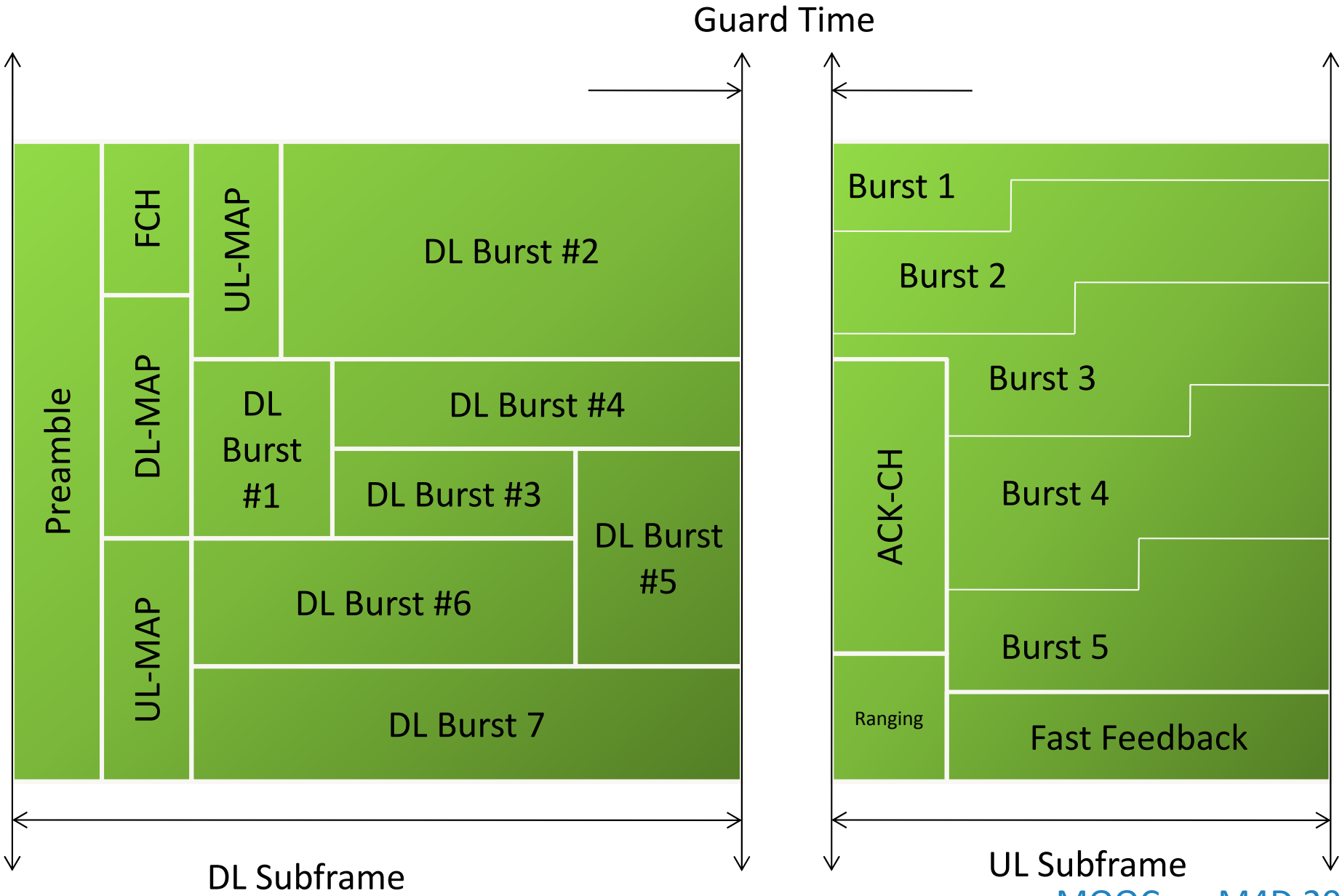
Flexible & Dynamic Resource Alloc.

- Both UL and DL resource allocation are controlled by a scheduler in the BS.
- Capacity is shared among multiple users on a demand basis, using a burst TDM scheme.
- Further, using the OFDMA-PHY mode, multiplexing is additionally done in the frequency dimension.
  - By allocating different subsets of OFDM subcarriers to different users.
- Resources may be allocated in the spatial domain employing Advanced Antenna Systems (AAS).

OFDMA Resource Allocation



WiMAX Frame Structure



WiMAX Scheduling Services

- MAC uses a *scheduling service to deliver and handle services* with different QoS reqs.
- Determines the mechanism the network uses to allocate UL and DL resources for the services.

WiMAX Scheduling Services

Scheduler type	Services
Unsolicited grant services (UGS):	Support for fixed-size data packets at a constant bit rate (CBR). - Voice
Real-time polling services (rtPS):	Designed to support real-time service flows, such as MPEG video, that generate variable-size data packets on a periodic basis. - Video
Non-real-time polling service (nrtPS):	Designed to support delay-tolerant data streams, such as an FTP, that require variable-size data grants at a minimum guaranteed rate.
Best-effort (BE) service:	Supports data streams, such as Web browsing, that do not require a minimum service-level guarantee. – Internet, e-mail
Extended real-time variable rate (ERT-VR) service	For real-time applications, such as VoIP with silence suppression, that have variable data rates but require guaranteed data rate and delay.

Mobility Support

- WiMAX supports the following types of mobility

Type	Features
Nomadic.	The user is allowed to take a fixed subscriber station and reconnect from a different point of attachment.
Portable.	Nomadic access is provided to a portable device, such as a PC card, with expectation of a best-effort handover.
Simple mobility.	The subscriber may move at speeds up to 60 kmph with brief interruptions (less than 1 sec) during handoff.
Full mobility:	Up to 120 kmph mobility and seamless handoff (less than 50 ms latency and <1% packet loss) is supported.

Network Architecture

Reference Network Architecture

AAA	Authentication, Authorization, Accounting
ASN-GW	Access Service Network Gateway
ASP	Application Service Provider
MIP-HA	Mobile IP Home Agent
MS	Mobile Station
OSS	Operational Support Systems
BSS	Business Support Systems