Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** <**http://grouper.ieee.org/groups/802/20/**>
Title	**Initial Contribution on a System Meeting MBWA Characteristics**
Date Submitted	**2003-03-06**
Source(s)	Samir Kapoor 135 Route 202/206 South Bedminster, NJ 07921 Voice: 908-997-2000 Fax: 908-947-7090 Email: s.kapoor@flarion.com Junyi Li 135 Route 202/206 South Bedminster, NJ 07921 Voice: 908-997-2000 Fax: 908-947-7090 Email: j.li@flarion.com
Re:	IEEE 802.20 Session#1 Call for Contributions
Abstract	To provide an overview of the PHY and MAC layers of a system that meets the desired characteristics for MBWA.
Purpose	For informational purposes only
Notice	
Release	
Patent Policy	

Initial Contribution on a System Meeting MBWA Characteristics

Samir Kapoor and Junyi Li
Flarion Technologies

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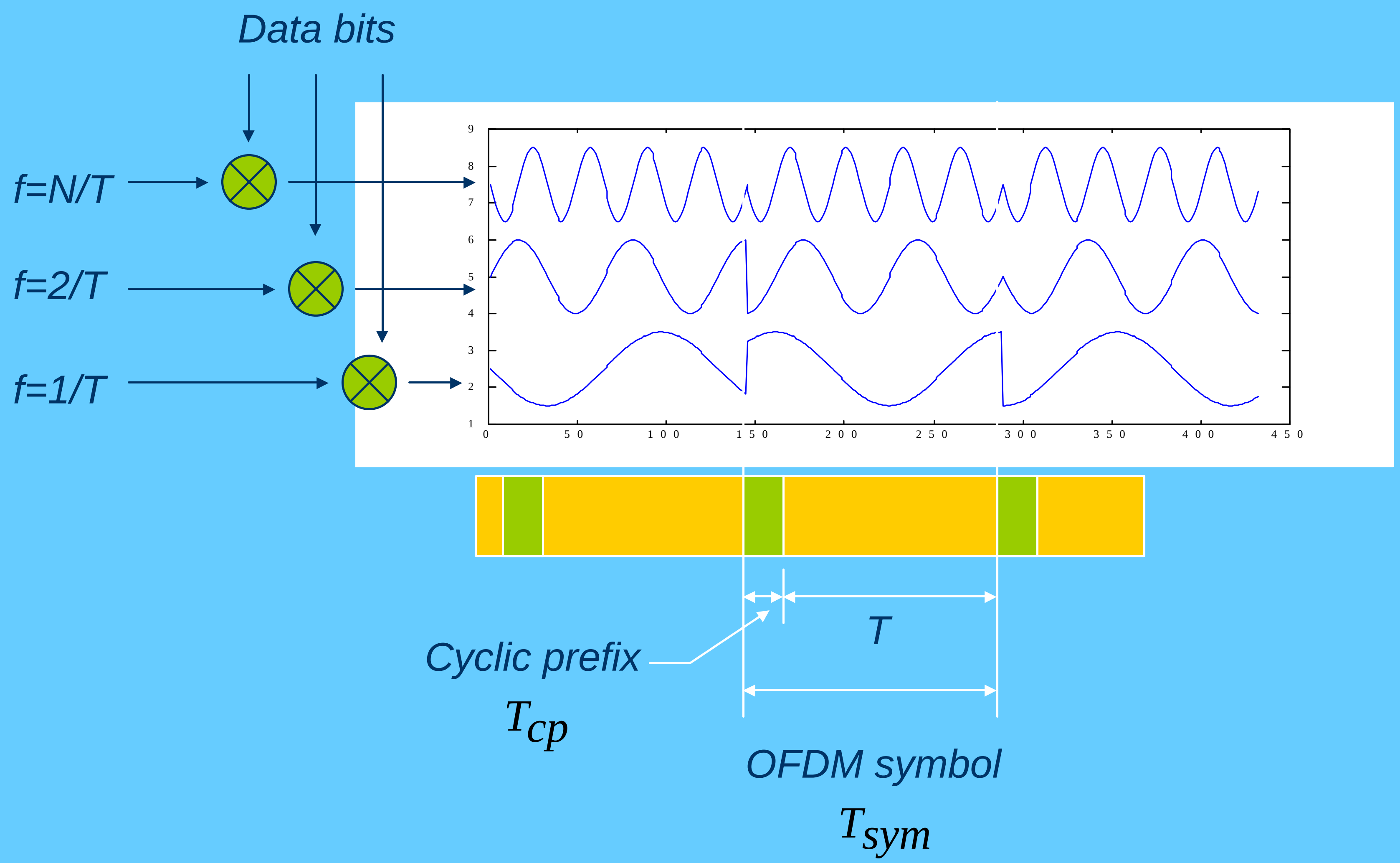
PHY Outline

- OFDM Basics
- PHY Features
  - Frequency Hopping
  - System Parameters
  - Channel Structure
  - Uplink Access
  - Traffic Channel
- Summary

OFDM Modulation



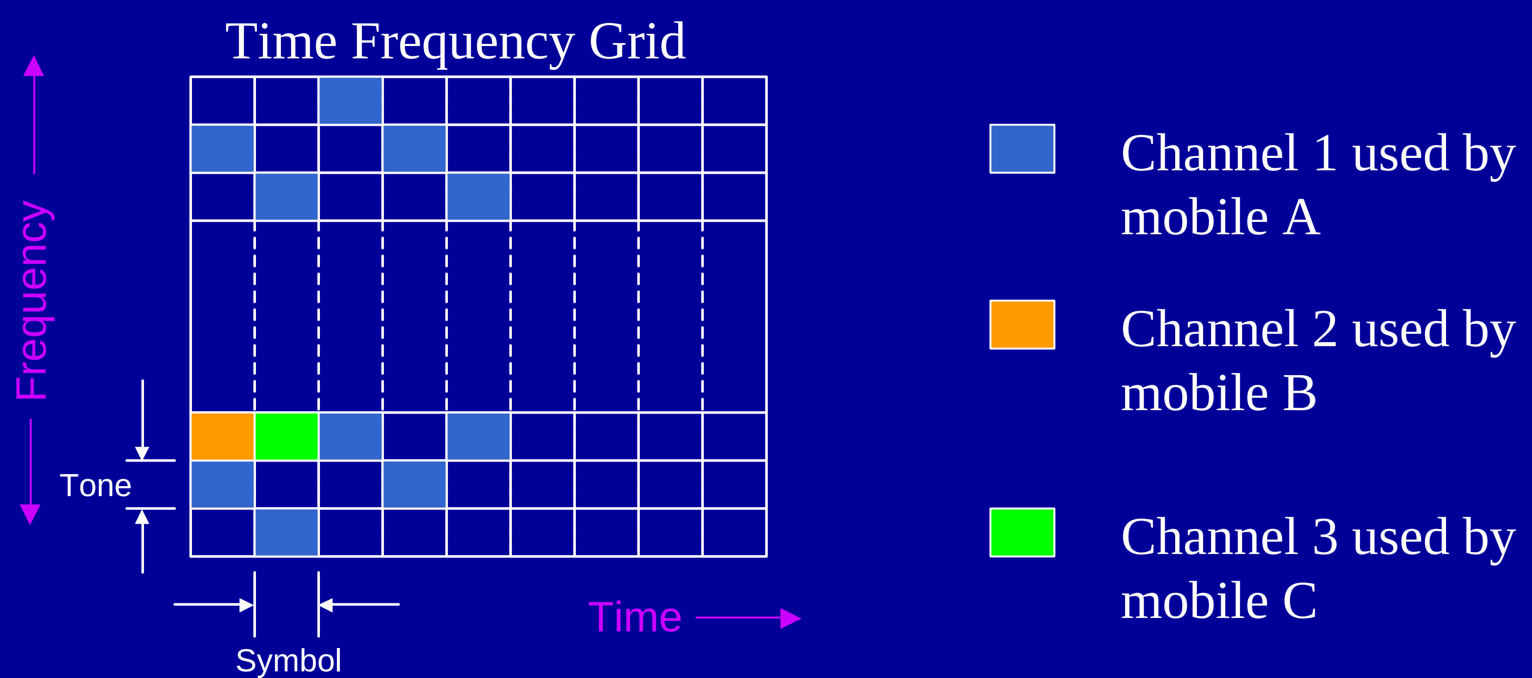
OFDM for Wireless Communications

- Using the appropriate configuration, OFDM tones of different frequencies maintain their *orthogonality* even in the presence of multipath delay spread
- Sinusoidal waveforms (tones) are the only functions that preserve orthogonality over multipath wireless channels. Walsh codes in DS-CDMA are no longer orthogonal after multi-path delay spread.
- With OFDM, the wireless channel for each tone has no intersymbol interference, and can be equalized with a one-tap equalizer.

OFDM-based Spread Spectrum Multiple Access

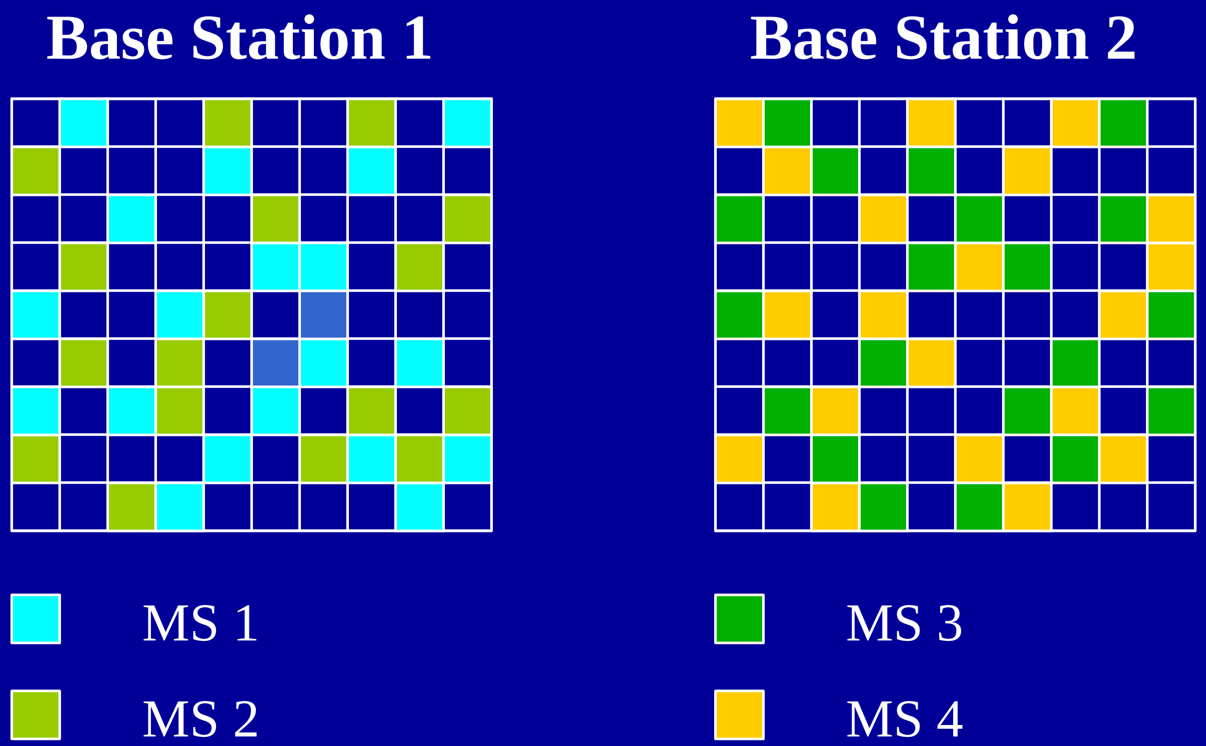
- OFDM for orthogonal multiple access
  - Different mobiles in a cell use different sets of tones
  - No intra-cell interference: *much higher capacity than CDMA*
- Fast tone hopping
  - Frequency diversity
  - Averaged inter-cell interference: *reuse factor = 1*
- Granularity of channel resource as small as a single tone in a single OFDM symbol
  - Rapid transmission of short (control) messages
  - Efficient sharing of channel resource among mobiles

Time-Frequency Channel Resource



- No inter-carrier interference (ICI)
- No inter-symbol interference (ISI)
- Each tone in each symbol can be independently used by different channels and mobiles

Cellular Network



- Different hopping patterns are used in adjacent cells to average inter-cell interference

Comparison

	TDMA/FDMA	CDMA	Frequency Hopped OFDM
In-cell interference	Users are orthogonal	Users non-orthogonal	Users are orthogonal
Out-of-cell interference	Must design for worst-case. No freq re-use	Users see average interference	Users see average interference

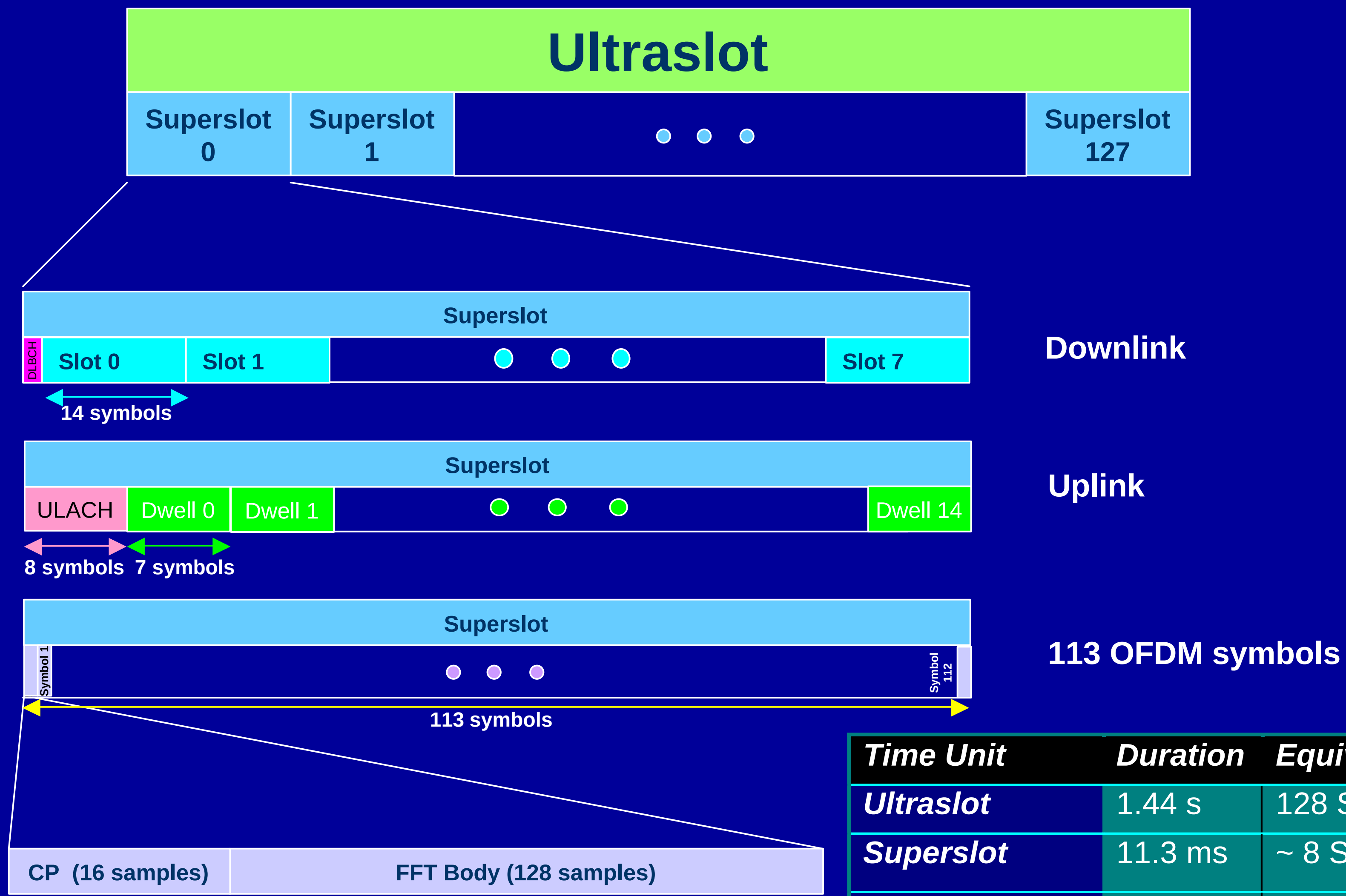
Basic System Parameters

Carrier frequency	Up to 3.5 GHz
Channel Bandwidth	1.25 MHz FDD
FFT size	128 (~88.8 us)
Cyclic prefix	16 (~11.1 us)
Tone spacing	11.25 KHz
Symbol rate	10 KHz
Tones used	113

Rationale behind Parameters

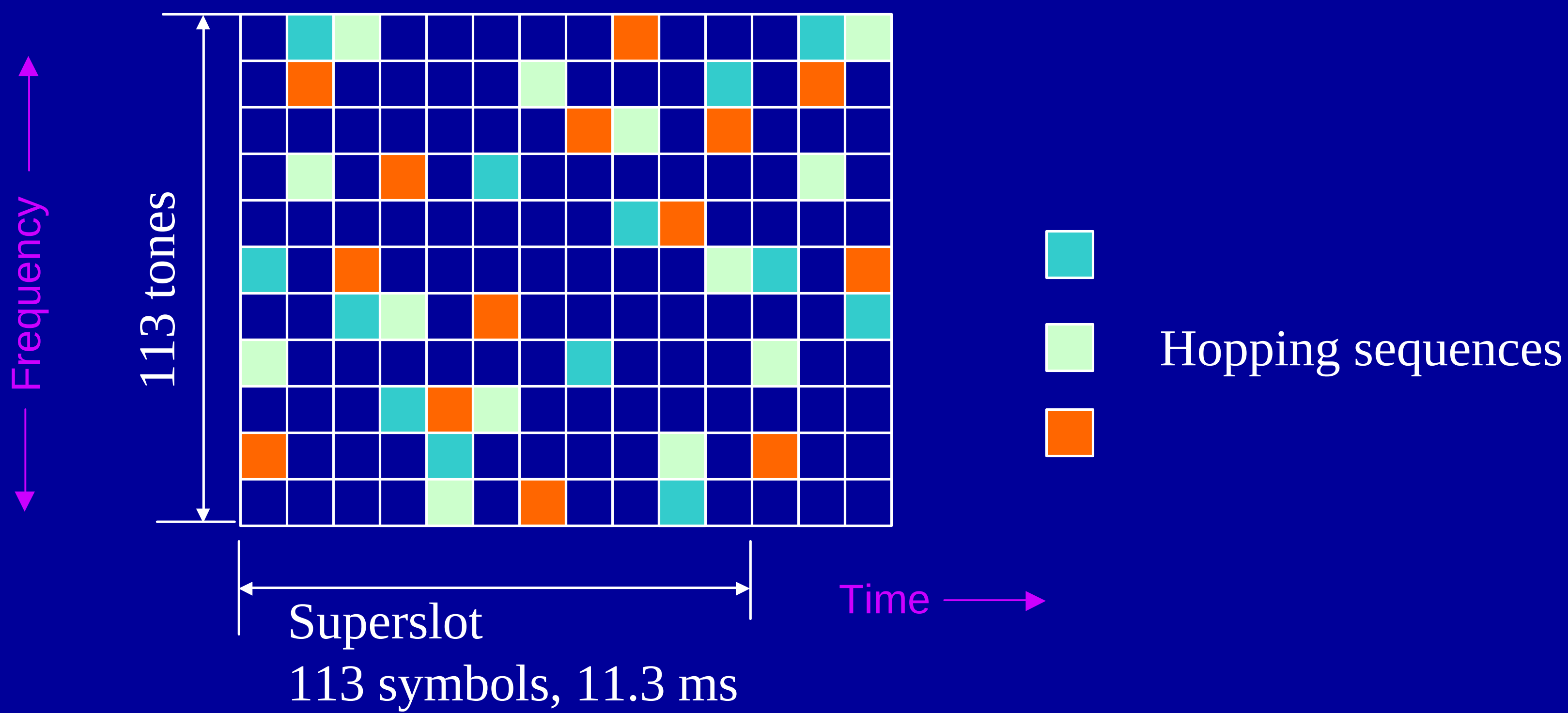
- Cyclic prefix length captures expected channel delay spreads
- OFDM Symbol duration
  - Large ratio between useful and cyclic prefix durations (8:1 or 88.8%)
  - Small compared to expected coherence times
- Inter-carrier spacing
  - Much greater than expected Doppler frequencies
  - Small compared to expected coherence bandwidths

Time Structure



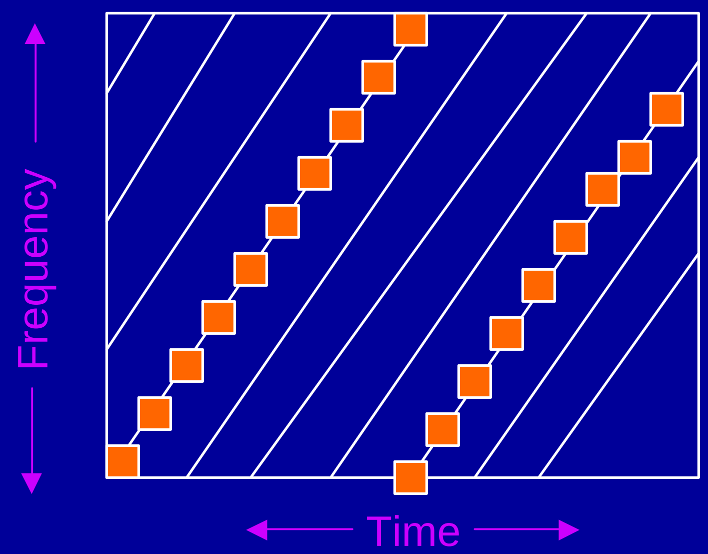
Time Unit	*Duration*	*Equivalent to*
Ultraslot	1.44 s	128 Superslots
Superslot	11.3 ms	~ 8 Slots
Slot	1.4 ms	2 Dwells
Dwell	0.7 ms	7 Symbols
Symbol	0.1 ms	

Downlink Hopping



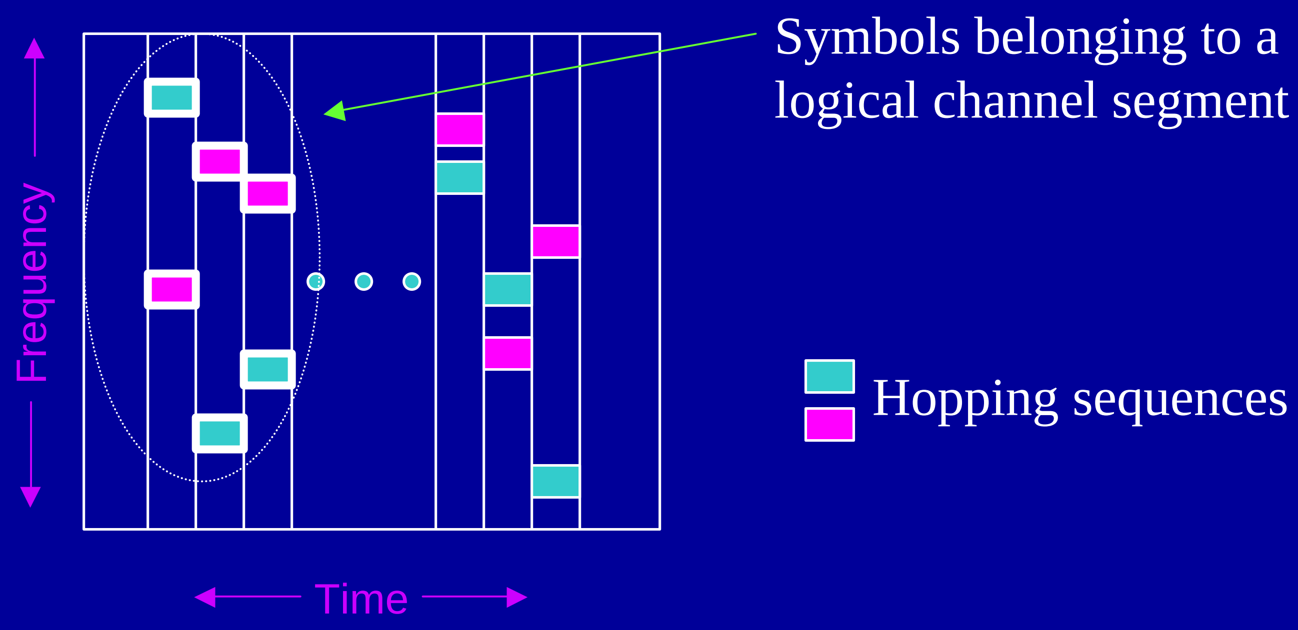
- Symbol by symbol hopping
- Hopping sequences periodic with a super slot
- Hopping sequences different for adjacent cells

Downlink Pilots



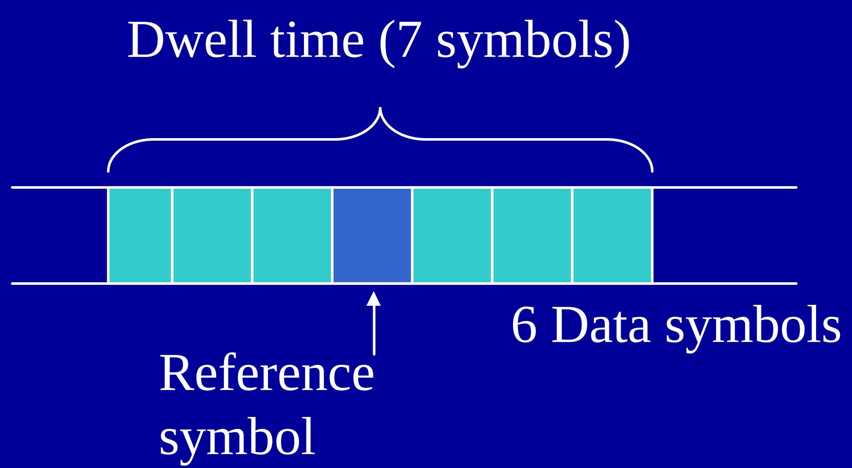
- Used for channel estimation, BS identification, downlink synchronization
- Modularly linear hopping across time-frequency space with periodicity of a super slot
- Each BS has unique pilot “slope”
- Pilots from neighboring BS collide at most once per super slot

Downlink Channels



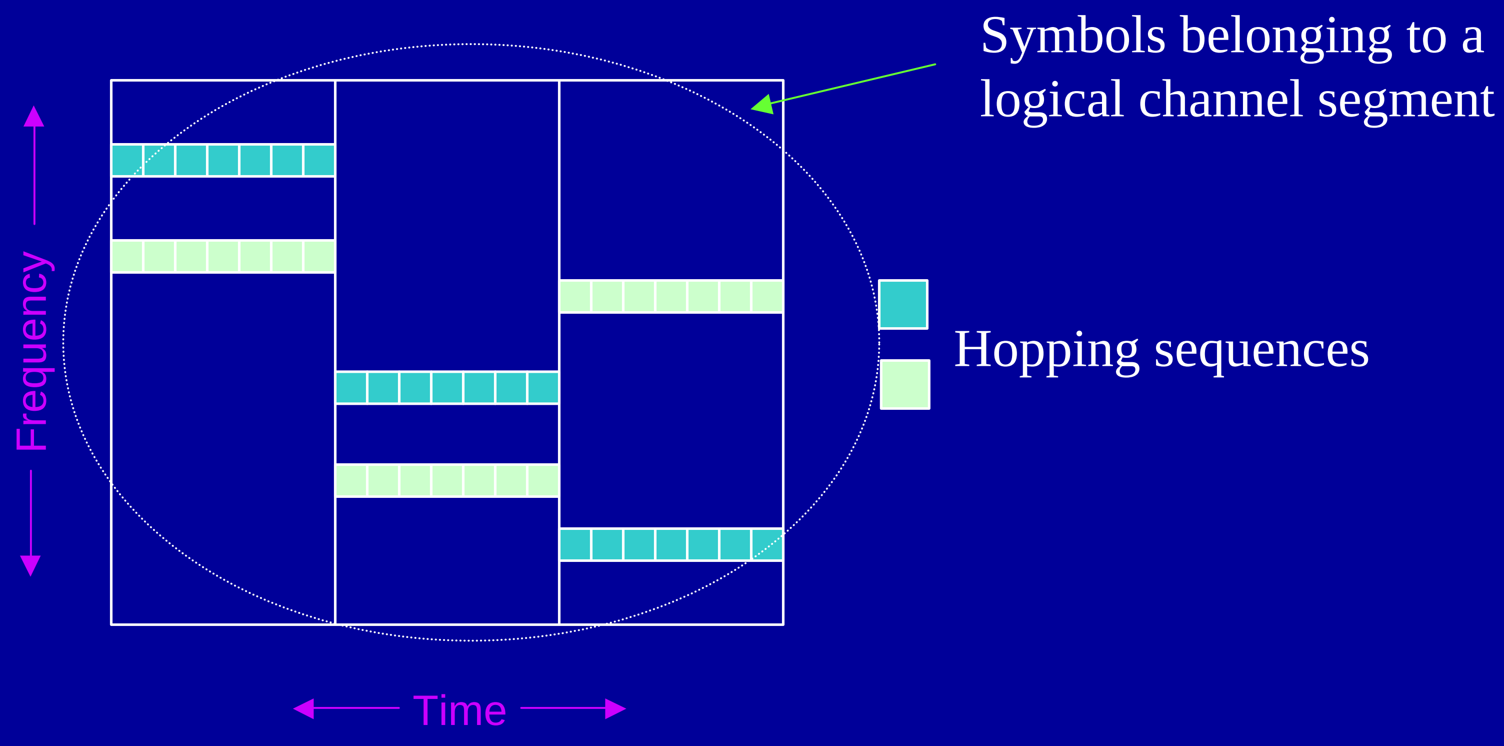
A logical channel consists of a series of channel segments, each of which is constructed with some hopping sequences over certain time duration

Uplink Hopping

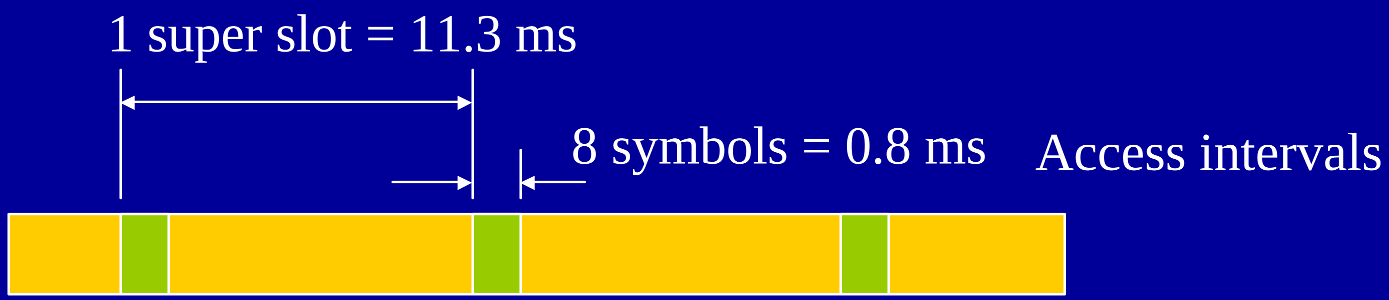


- In uplink, tones hop once every 7 OFDM symbols
- Since there are no shared uplink pilots, data is modulated in each dwell time with one reference symbol
- Hopping sequences different for adjacent cells

Uplink Channels

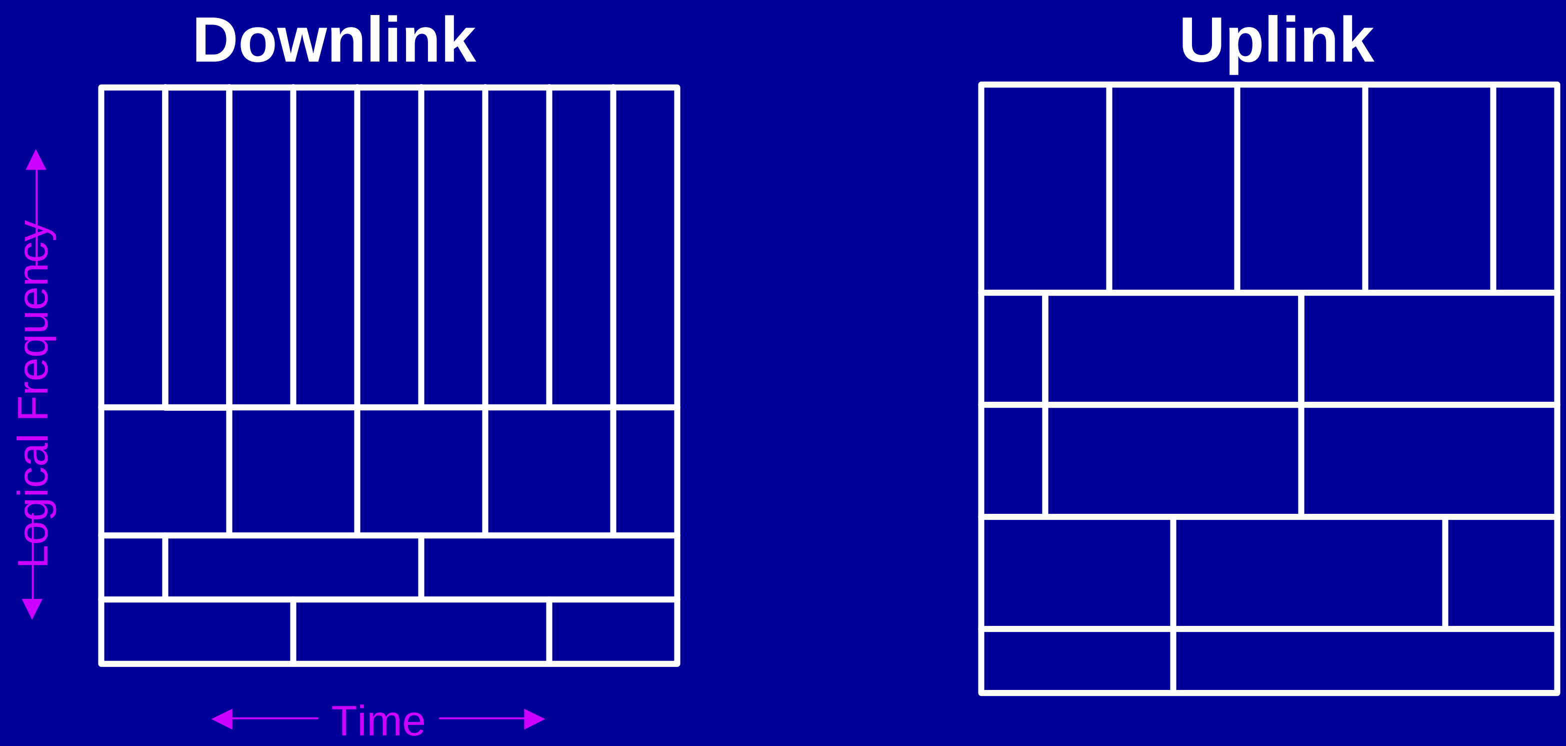


Uplink Access



- Access intervals
  - Separate from data intervals
  - Used by access mobiles, which are not yet uplink-synchronized
  - Used by existing mobiles for periodic timing tracking
- Access signaling
  - An access signal is a multi-tone signal, providing diversity and timing resolution
  - Access signals can be detected with low processing complexity
  - Only access signals are contention-based. After access, all signaling is contention-free.

Traffic Channel Illustration



- A traffic channel segment consists of a number of tones over a fixed (short) time interval
- Traffic channel segments can be of different time/frequency “shape” to enable joint optimization of power, bandwidth and rate
- Each traffic channel segment can be separately allocated

Modulation and Coding for Traffic Channels

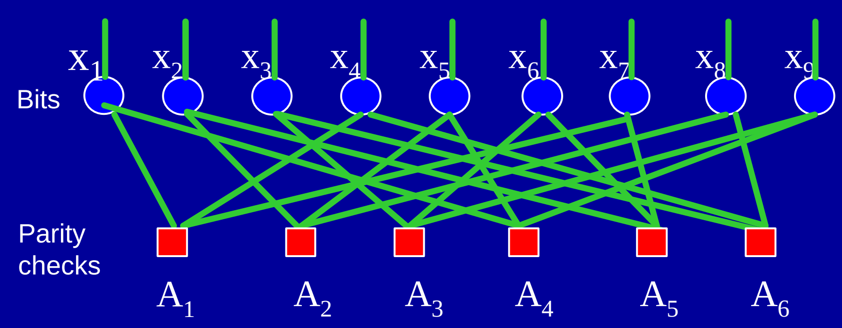
Traffic Channel	Code Type	Code Rate	Length	Modulation
DL Traffic Channel	LDPC	1/6 to 5/6	1344, 2688,…	QPSK, 16QAM,…
UL Traffic Channel	LDPC	1/6 to 5/6	1344	QPSK

- Error control codes
  - Low-Density Parity-Check (LDPC) codes
  - Various code rates from ~1/6 to ~5/6
  - Codewords are long enough to obtain high coding gain, but short enough to keep latency low.
- Modulation constellations
  - QPSK, 16-QAM, …
- Aggregate peak rates
  - DL > 4 Mbps
  - UL > 800 Kbps

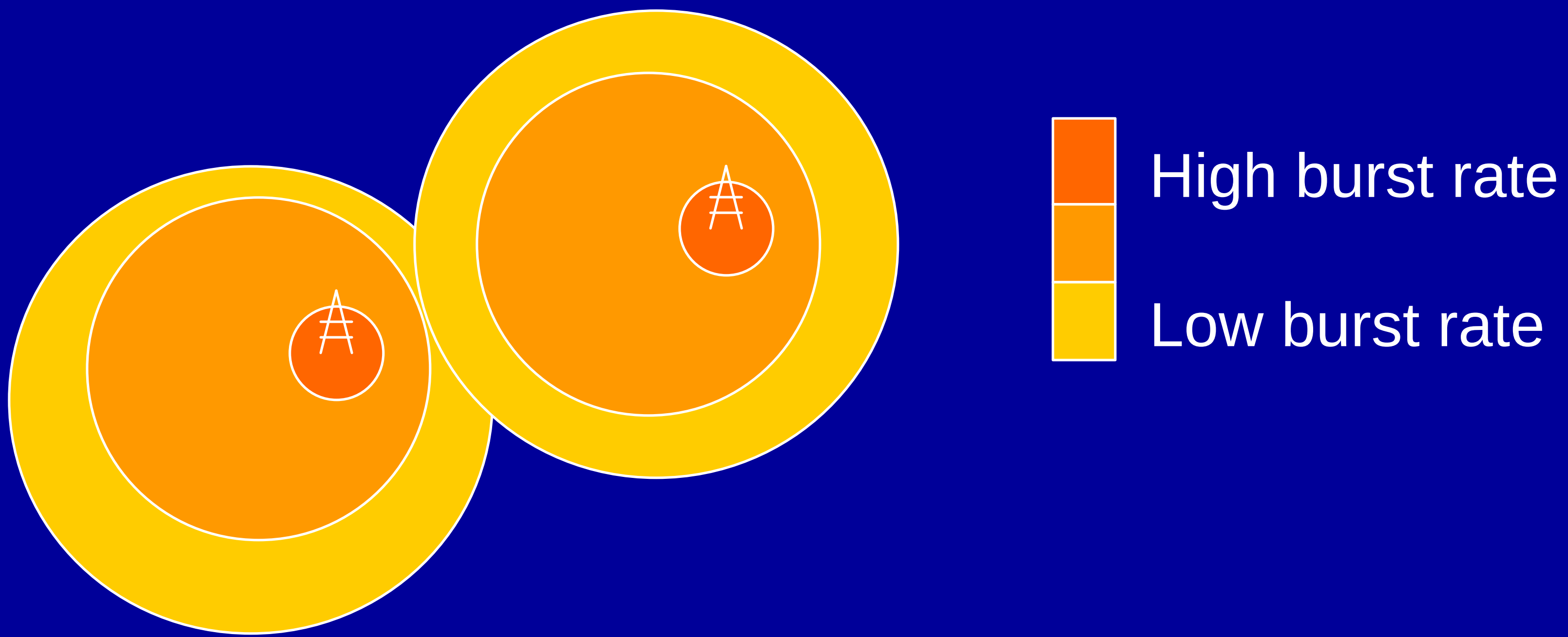
LDPC Codes

- Low-Density Parity-Check (LDPC) Codes
  - Decodable using iterative “message-passing” algorithm
  - Encodable using efficient algorithms
  - Offers significant coding gain
- Advantages of LDPC over Turbo Codes
  - Lower complexity for decoding algorithm
  - Inherent parallelism in message-passing algorithm enables efficient hardware implementations
  - LDPC code designs can offer better performance

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_9 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$



Adaptive Coding and Modulation



- Coding and modulation scheme can be independently allocated on a per segment basis
- Burst rates can be adaptively adjusted based on downlink channel condition and power allocation
- Mobiles frequently report their channel conditions to facilitate adaptive coding and modulation

PHY Summary

- High spectral efficiency
  - Orthogonality within a cell
  - Interference averaging between cells
  - Adaptive coding and modulation
- Fine granularity for allocating system resources
  - Rapid transmission of short (control) messages
  - Efficient sharing of channel resource among mobiles
- Efficient access with minimum contention

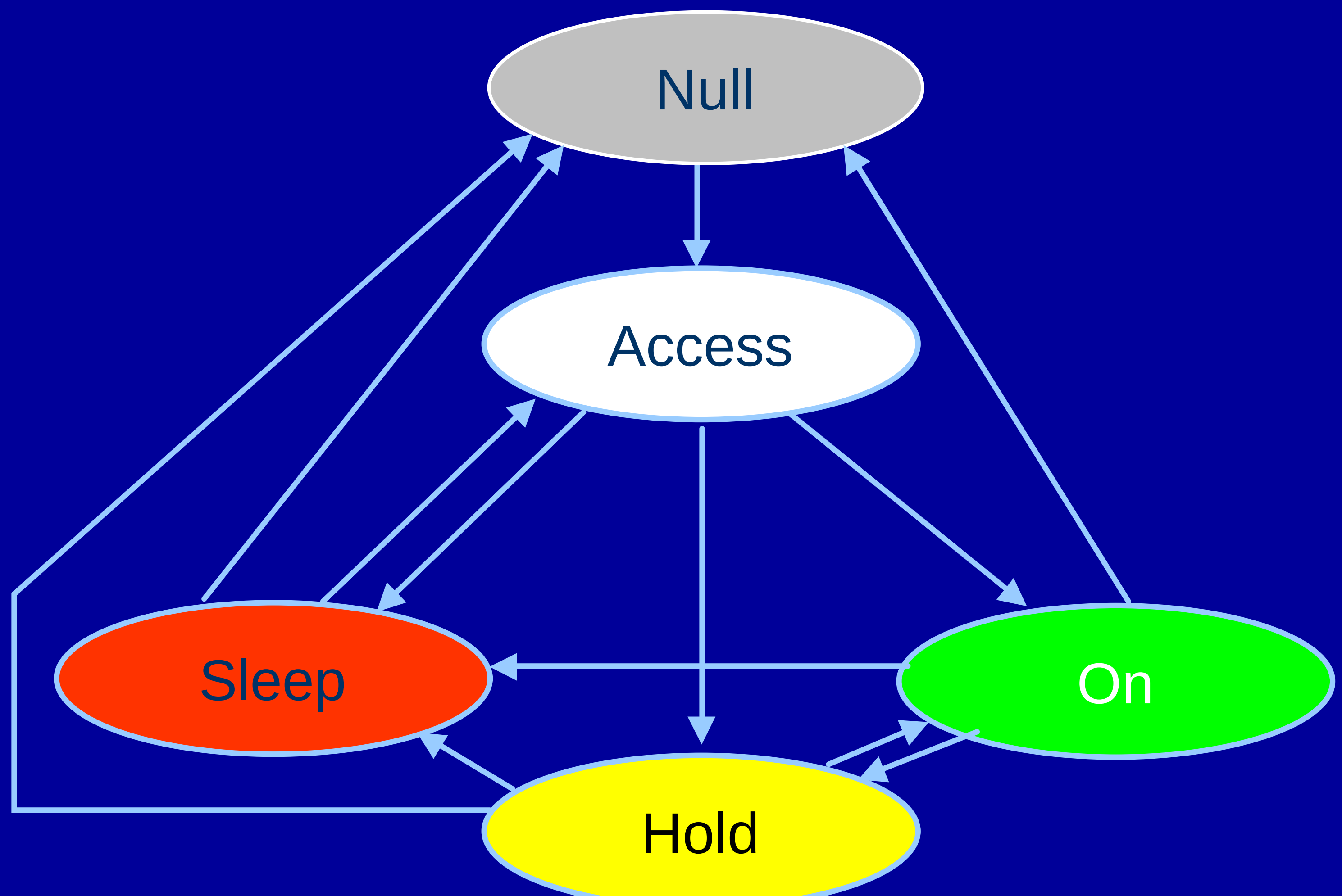
MAC Outline

- MAC States
- Downlink and Uplink Channels
- MAC state operation
  - Access
  - On
  - Hold
  - Sleep
- Summary

MAC Features

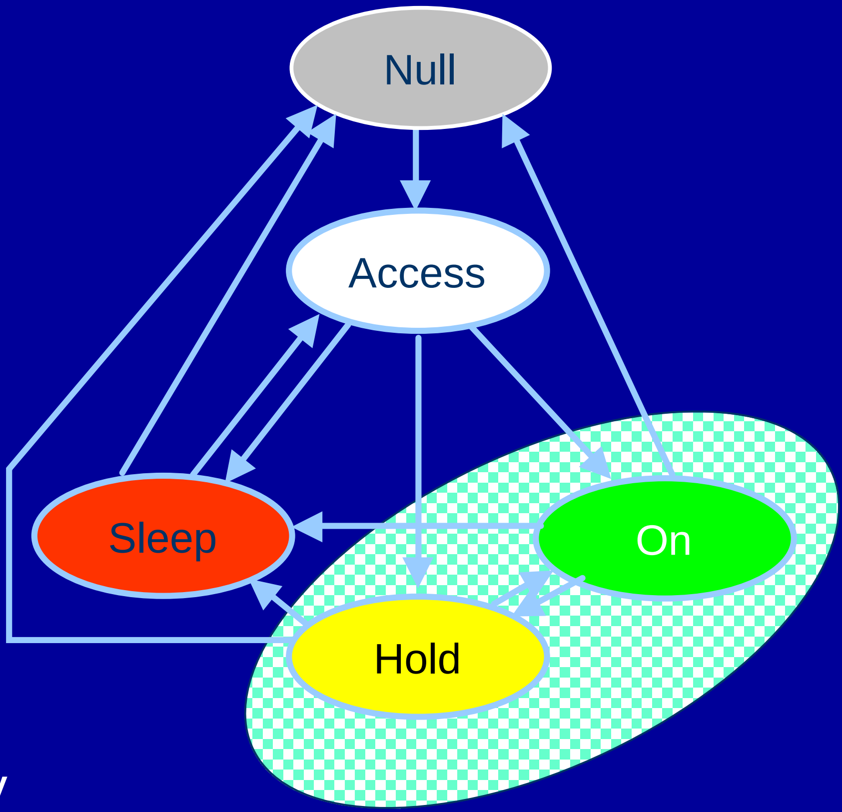
- Fine granular channel structure based on OFDM PHY
  - Efficient, flexible partition of airlink resources
- Optimized to support large number of data users with multiple states
  - On
  - Hold
  - Sleep
- Low latency and fast ARQ
- Facilitates multiple scheduling options per operator needs

MAC States and Transitions



Active (On and Hold) MAC states

- Rapid state transitions
  - Very low overhead
  - Dedicated resources
  - Deterministic timeframe
- Results in
  - Reduced control overhead for Active-hold users
  - Reduced interference
  - Significantly enhanced mobile battery life
  - Dramatic increase in user capacity



Downlink Channels used in MAC States

	Data traffic	Control	State transitions
Access state			Access Grant (AGCH) Access Exchange (AXCH)
On state	Traffic (TCH)	Traffic Control (TCCH) Power Control (PCCH) Broadcast (BCH)	State Transition (STCH)
Hold state	Limited TCH	Traffic Control (TCCH) Broadcast (BCH)	State transition (STCH)
Sleep state			Paging (PCH)

- The Traffic Control Channel (DLTCCH) includes DL/UL assignments and ACKs for ULTCH.
- The Broadcast Channel (DLBCH) includes timing control.
- The base station also transmits pilots and nulls.

Uplink Channels used in MAC States

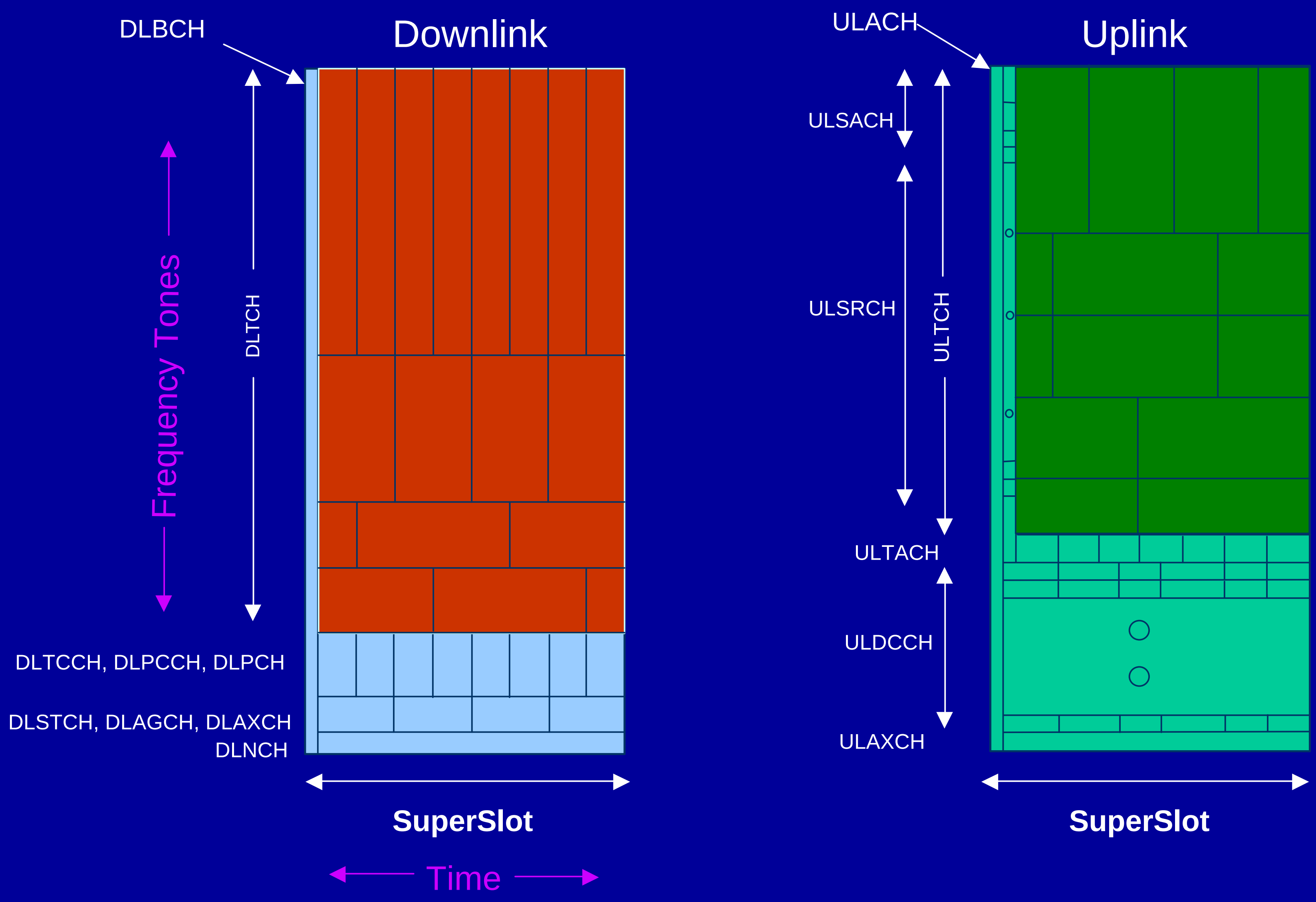
	Data traffic	Control	State transitions
Access state			Access (ACH) Access Exchange (AXCH)
On state	Traffic (TCH) Traffic ACK (TACH)	Dedicated Control (DCCH) Timing Control (ACH)	State Transition ACK (SACH)
Hold state	Traffic ACK (TACH)	Timing Control (ACH)	State Transition ACK (SACH) State Transition Req. (SRCH)
Sleep state			Paging Ack (PACH)

- The Dedicated Control Channel (ULDCCH) includes UL traffic requests and reports on the DL channel quality.
- The UL ACK Channel (ULTACH) is for the DL Traffic (DLTCH).

Channel Acronyms

- Downlink (DL*CH)
  - **DLBCH**: Broadcast
  - **DLTCH**: Traffic
  - **DLTCCH**: Traffic Control
  - **DLPCCH**: Power Control
  - **DLSTCH**: State Transition
  - **DLPCH**: Paging
  - **DLAGCH**: Access Grant
  - **DLAXCH**: Access Exchange
  - **DLNCH**: Null
- Uplink (UL*CH)
  - **ULACH**: Access
  - **ULTCH**: Traffic
  - **ULTACH**: Traffic Ack
  - **ULDCCH**: Dedicated Control
  - **ULAXCH**: Access Exchange
  - **ULSACH**: State Transition Ack
  - **ULSRCH**: State Transition Rqst

Overall MAC Channel Structure



DL Broadcast Channels

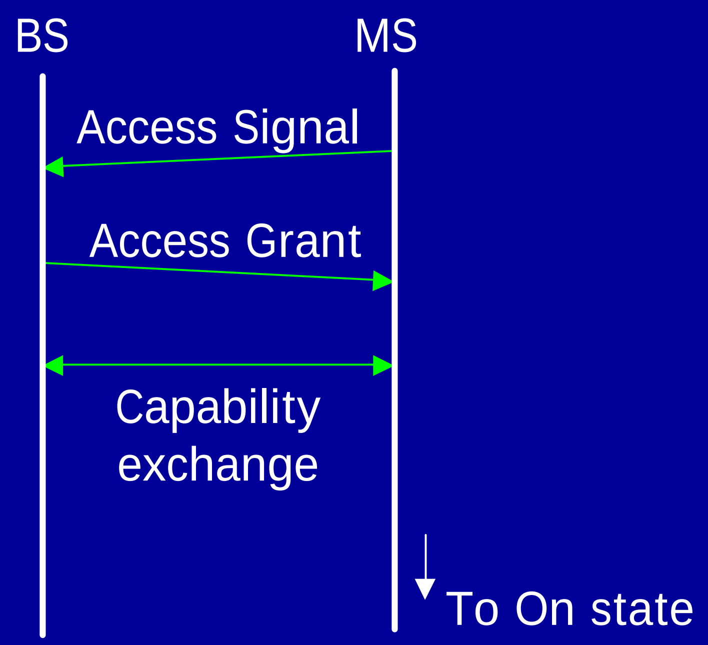
- Characteristics for MBWA
  - Transmits system information to all mobiles
  - Periodic and low overhead
  - Time multiplexing of strip symbol to obtain family of channels
- Features
  - Different channels have different periodicities
  - Occupies 1 OFDM symbol per super-slot (~1% DL overhead)
  - Sector information, BS Transmit parameters, Time-stamps, Synchronization parameters, Timing Control, Handoff parameters, System Configuration information etc.

MAC Outline

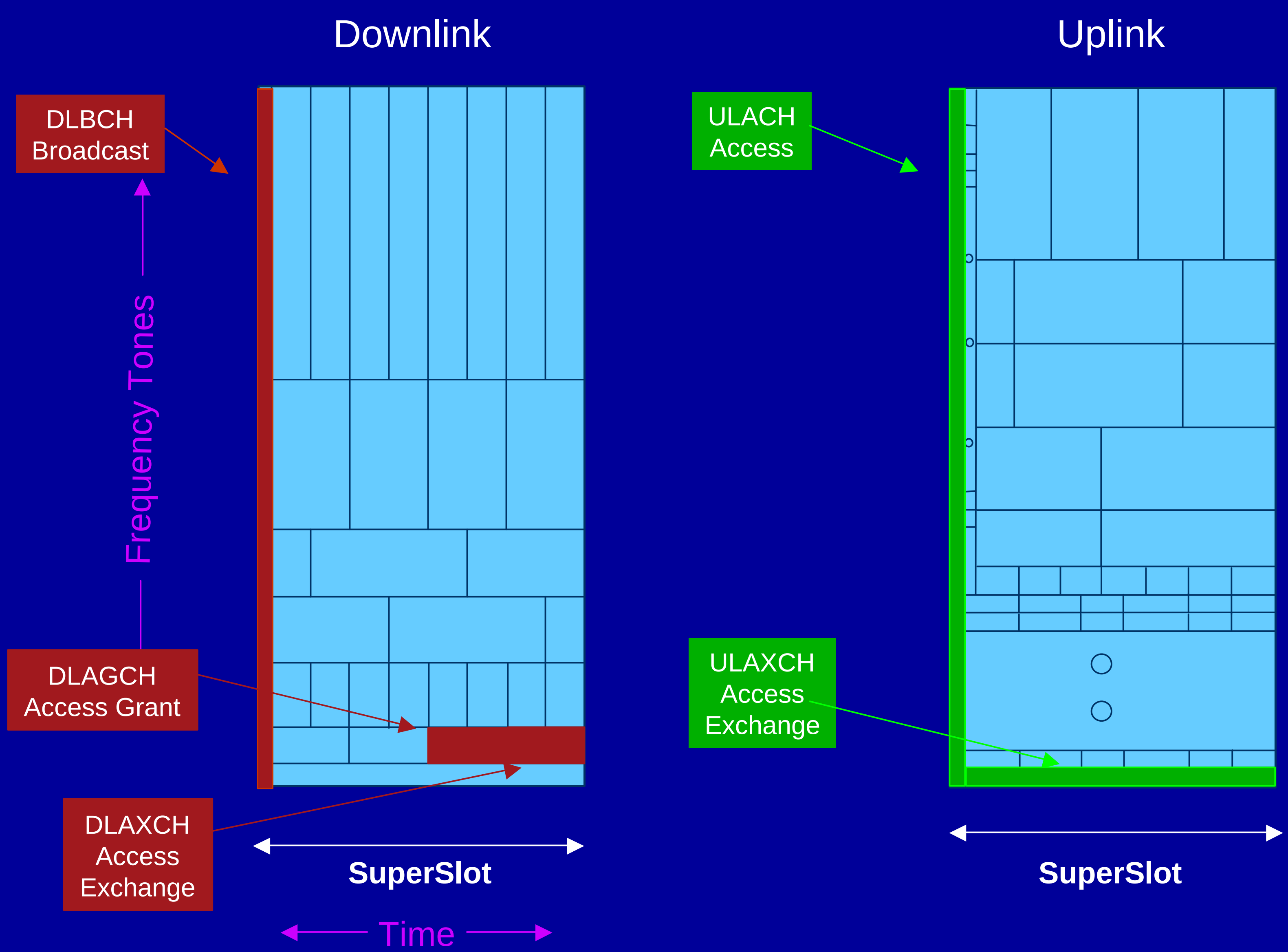
- MAC Features
- MAC States
- Downlink and Uplink Channels
- **MAC state operation**
  - Access
  - On
  - Hold
  - Sleep
- Summary

Uplink Access Channels

- Characteristics for MBWA
  - Contention-based resource for initial access
  - No interference with other channels
  - Incurs low overhead
  - Provides frequent opportunities
- Features
  - Dedicated access interval
  - Reduced collision probability with orthogonal waveforms
  - Collisions resolved on dedicated channel
  - MS and BS exchange relevant info on dedicated channel
  - Typical PHY access time within 50ms
  - Provides ~90 access opportunities/sec
  - Occupies ~7% of available UL tones



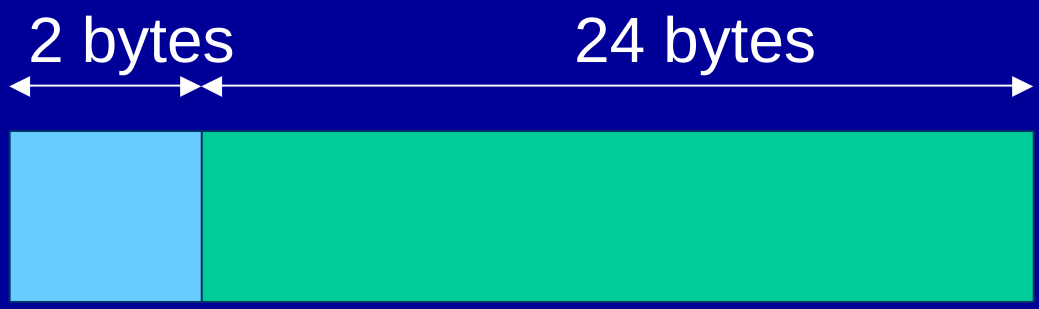
Access State Operation



Downlink Traffic *Control* Channel (DLTCCH)

- Characteristics for MBWA
  - Broadcasts assignment of DL and UL traffic segments to users in each slot
  - Acknowledges received UL Traffic segments
  - Allows fine granularity in traffic channel allocations
  - Facilitates low latency data transmission
  - Fast adaptation of coding & modulation options is commensurate with channel coherence time
  - Occupies only ~10% of available DL tones
- Features
  - BS Scheduler assigns multiple users in every 1.4ms slot
  - DL Traffic segments slaved to traffic control assignments
  - UL ACKs slaved to received UL Traffic segments

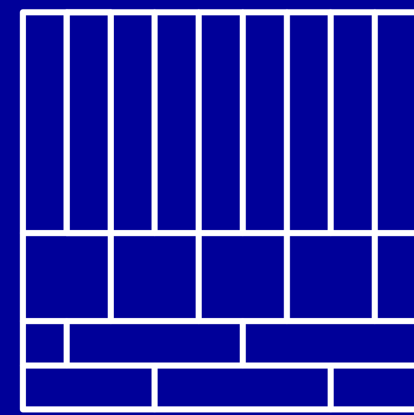
MAC Frame Format

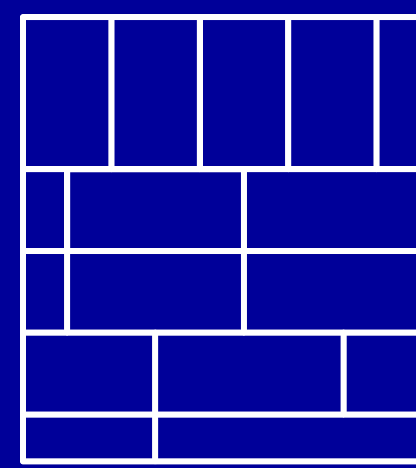


- 2 byte header + 24 byte payload
- MAC header information
  - ARQ
  - QoS
  - Packet boundaries
- CRC on per segment basis

Downlink and Uplink Traffic Channels (DLTCH, ULTCH)

- Characteristics for MBWA
  - Low overhead (e.g., for CRC, MAC frame headers)
  - Flexible granularity and allocation options
  - Supports multiple modulation and channel coding options
  - Carries data and selected control traffic
- Downlink
  - Multiple channel combinations
  - Multiple modulation and code rate options
  - Peak rate > 4 Mbps aggregate (or per user)
  - Occupies 85% of available DL tones
- Uplink
  - Multiple channel combinations
  - Multiple modulation and code rate options
  - Peak rate > 800 Kbps aggregate (or per user)
  - Occupies 68% of available UL tones

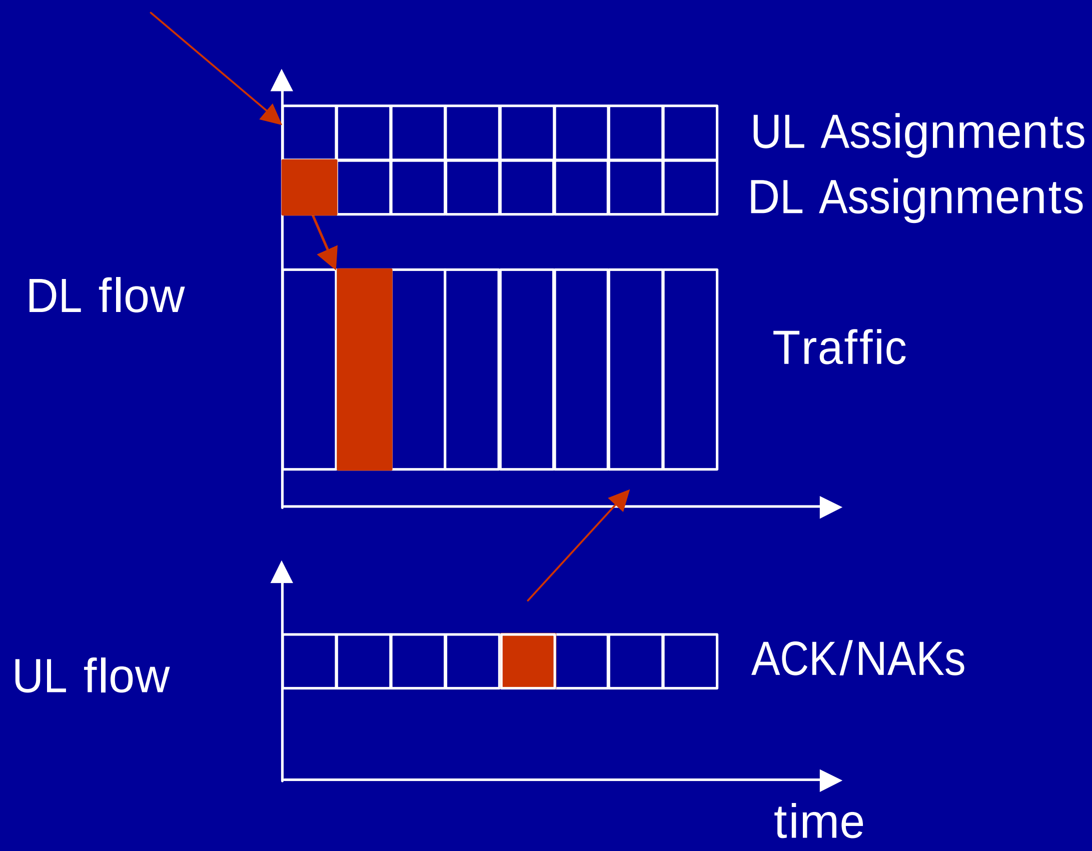




MAC Frame ACKs

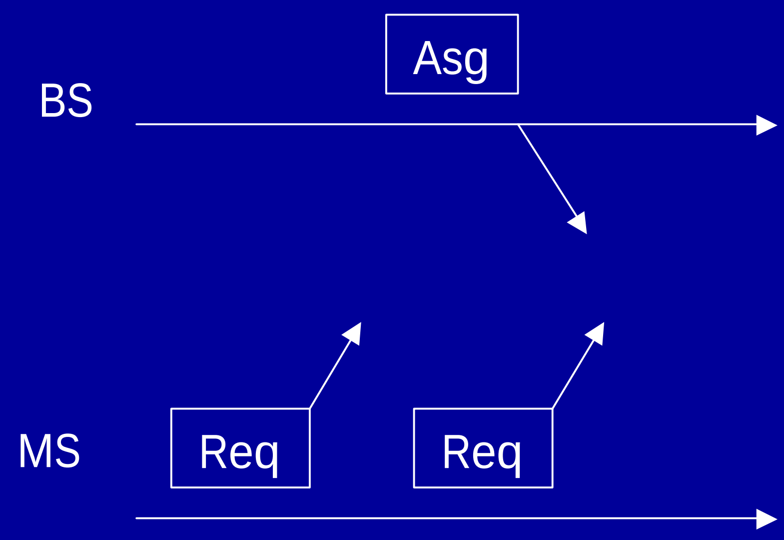
- Characteristics for MBWA
  - Contention-free resource per user
  - Fast, deterministic ACK/NAK response times
  - Very low bit rate overhead
  - Very low RTT delay/variation (including ARQ) minimally impacts end-to-end TCP RTT mean and variance estimates
- Downlink
  - 1 bit per UL Traffic Segment
  - < 1% of available DL tones (~1.2 Kbps overhead)
  - Slaved to UL traffic segments (deterministic response time)
- Uplink
  - 1 bit per DL traffic segment
  - < 1% of available DL tones (~1.4 Kbps overhead)
  - Slaved to DL traffic segments (deterministic response time)

Slaved Assignment, Traffic, ACK Illustration

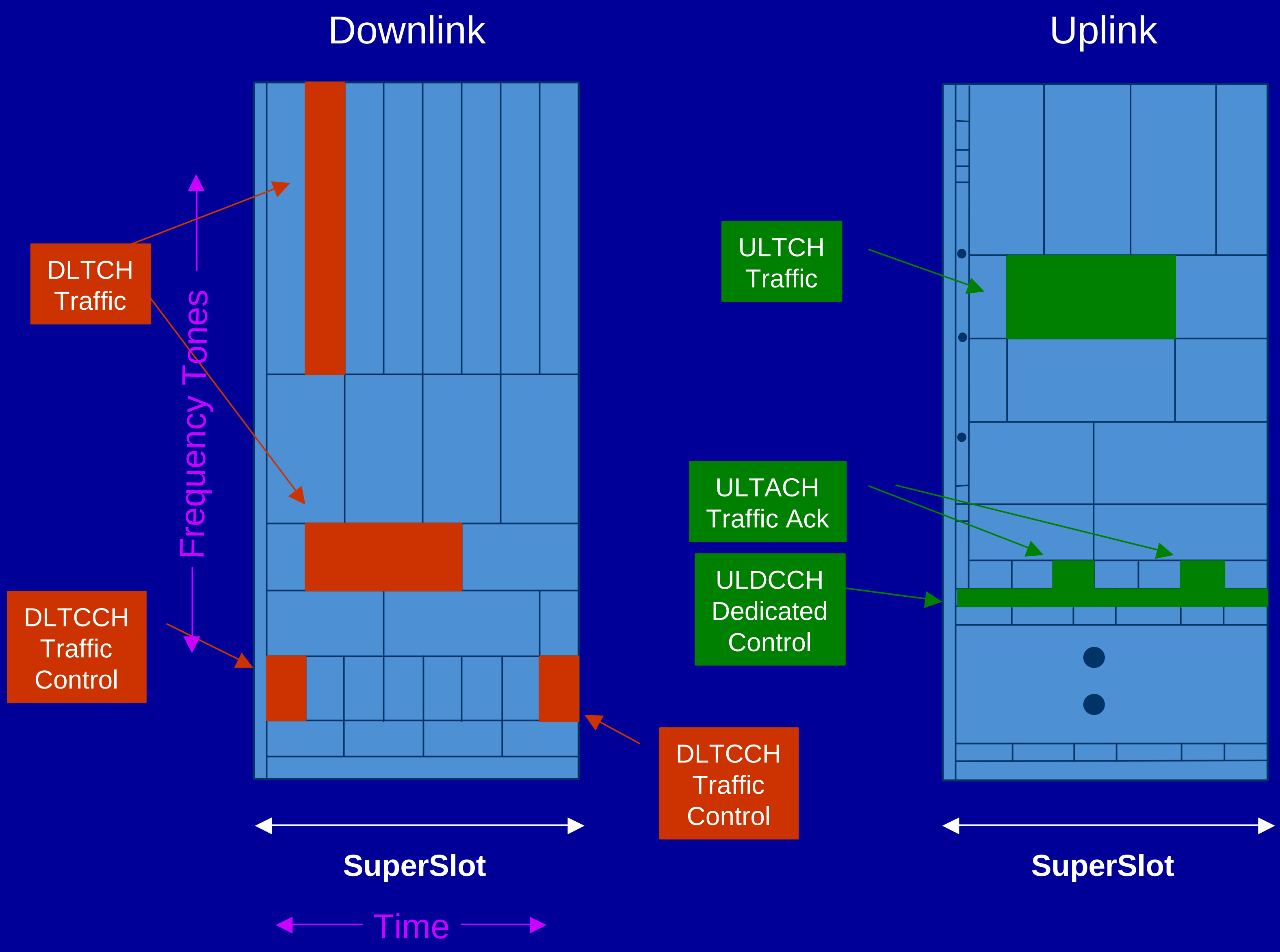


Uplink Dedicated Control Channel (ULDCCH)

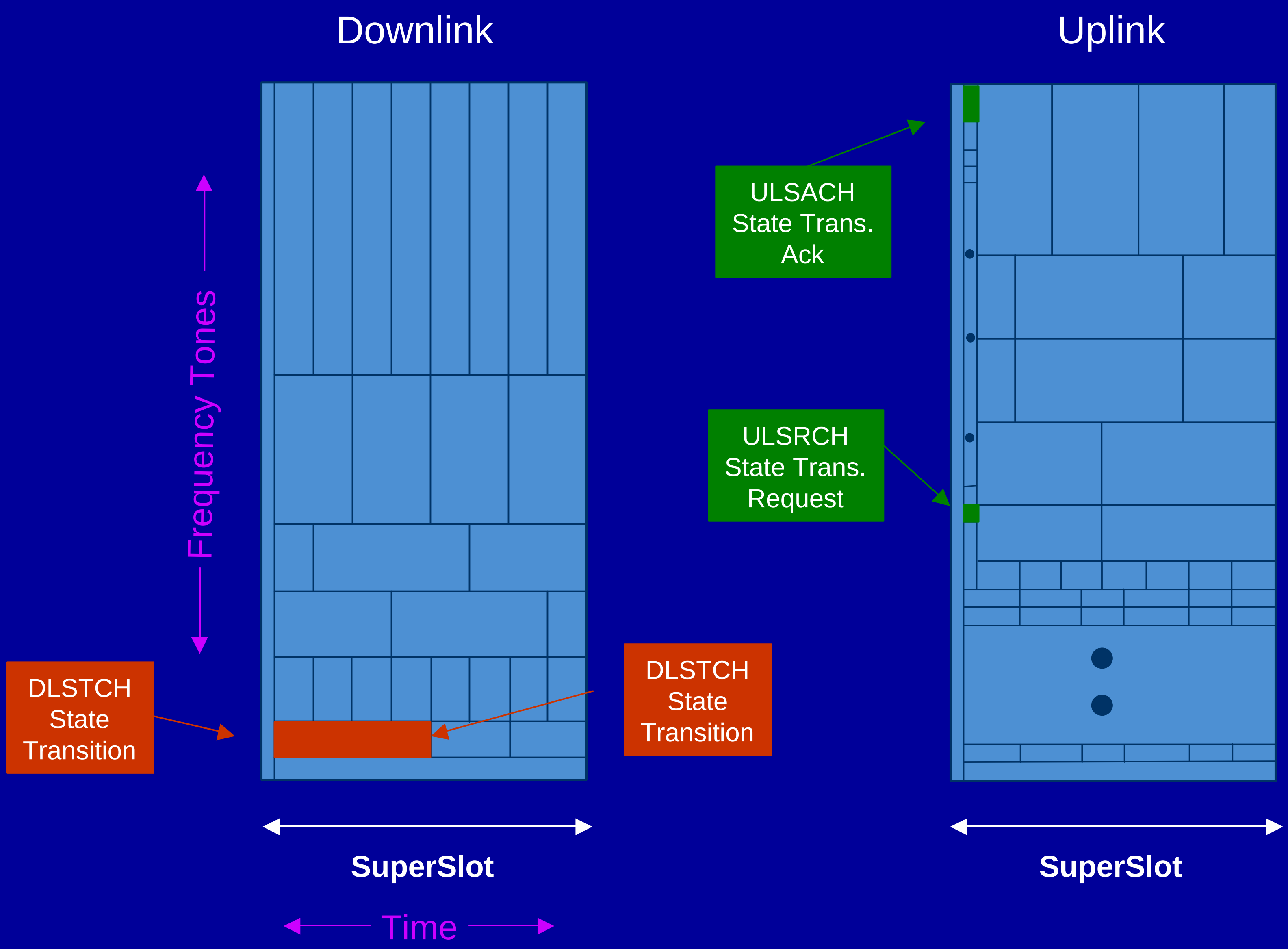
- Characteristics for MBWA
  - Fast DL channel quality feedback
  - Contention-free resource per user to request UL traffic slots
  - Fast, deterministic request time with very low overhead
  - Conveys request priorities for QoS
  - Contention-free request per On user approx. every 5ms



On State Operation



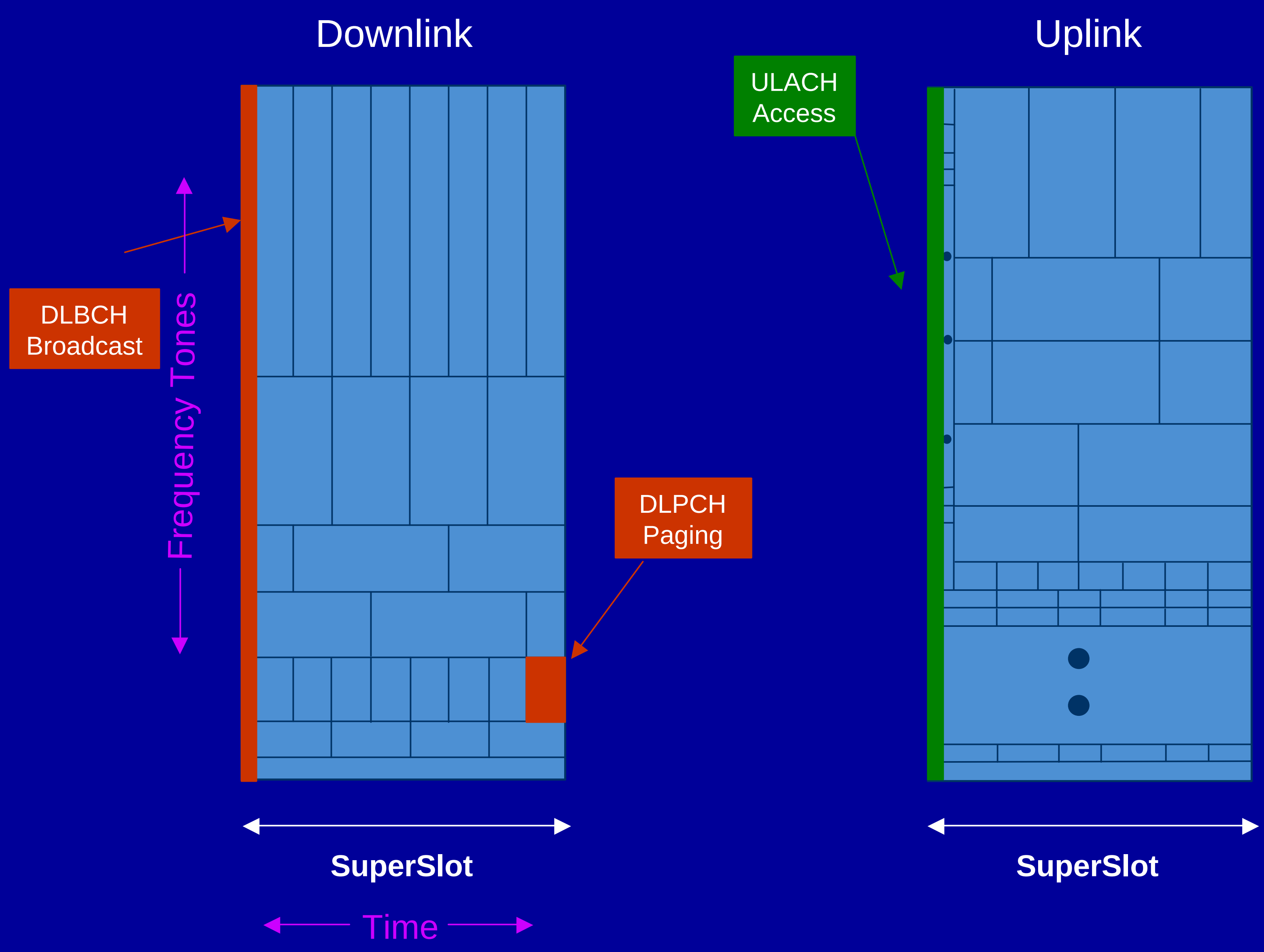
Transition between Active States



Paging over the Airlink

- Characteristics for MBWA
  - Fast “wake-up” for Sleep state mobiles
  - Supports very large number of Sleep users
  - Supports QoS via different periodicities
- Features
  - Paging frames are periodically sent to Sleep mobiles (as often as once every 90 ms)
  - The paging signal lasts for less than 1 ms, so the mobiles have very brief wake up duration
  - Mobiles re-enter system via Access mechanism

Sleep State Paging Operation



MAC States: Salient Features

- On State
  - Mobiles can transmit and receive data traffic with low latencies (milliseconds)
  - Full fledged uplink control channels
  - Supports rich QoS functionality
- Hold State
  - Limited uplink control channels
  - Rapid contention-free transition to On
  - Power save mode
  - Can also receive DL data traffic
- Sleep State
  - No uplink control channels
  - "Hibernation" power save mode
  - Large number of Mobiles supported

MAC Features

- OFDM PHY enables finely granular resource partitioning (time-slots, frequency tones)
- Key attribute for multiple access:
  - Smallest transmit/receive unit can be 1 bit
  - Allows for dedicated, low-overhead fast control channels
  - Efficient operation for “high-maintenance” bursty data connections
- Low cost of “starting and stopping” transmission of data traffic and control messages

MAC Features (cont'd)

- Optimized to support large number of data users
  - Multiple states – On, Hold, Sleep
  - Fast transitions between states, with QoS
  - No contention for Active (On and Hold) users
- Low latency and fast ARQ
  - Interactive apps (Gaming, VoIP), TCP/IP
  - Higher <u>sustained</u> data rates
- Facilitates multiple scheduling options per operator needs
  - Fairness constraints, QoS

Summary

- MAC is tightly integrated with PHY
- Takes fundamental advantage of OFDM
- Lightweight control channel structure
- Supports low, deterministic latencies
- Reliable link through fast ARQ
- Multiple states with fast transitions allow for large user capacity
- Enables sophisticated QoS infrastructure
- Enables vehicular speed hand-offs without packet loss
- Enables power saving modes for mobiles