Project	IEEE 802.20 Working Group on Mobile Broadband Wireless Access <http://grouper.ieee.org/groups/802/20/>
Title	**UMBFDD Overview Presentation**
Date Submitted	5 March 2007
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Re:	MBWA Call for Proposals (802.20 - 07/02)
Abstract	This contribution contains an overview presentation of the UMBFDD proposal. It is part of the UMBFDD proposal package.
Purpose	For consideration by 802.20 as it evaluates proposals for FDD MBWA.
Notice	
Release	
Patent Policy	

UMBFDD Overview

Contents

- General Overview
- Physical Layer
- MAC Layer
- Upper Layers

Why UMBFDD?

- UMBFDD = Ultra Mobile Broadband FDD
- Meets/exceeds all 802.20 requirements (see compliance report in C.802.20-07/08)
- UMB^{TM} specs recently (02/07) completed (Review and Freeze phase) by 3GPP2
- Final approval phase (Validation and Verification, e.g. ballot in TIA) expected to complete in late April.

Key points

- **System designed for robust mobile broadband access**
  - **Broadband wireless system optimized for high spectral efficiency and short latencies using advanced modulation, link adaptation and multi-antenna transmission techniques**
  - **Features necessary for mobile operation such as fast handoff, fast power control, and inter-sector interference management are integrated into the design**

- **Historic Note:**
  - **Design work in the committees from January 2006 to March 2007**
  - **Starting point: "C30-20060731-040R4_HKLLMNQRSUZ_PP2_FDD_Proposal" from: China Unicom, Huawei Technologies, KDDI, LG Electronics, Lucent, Motorola, Nortel Networks, QUALCOMM Incorporated, RITT, Samsung Electronics, ZTE Corporation.**
  - **Many others have contributed significantly since**
  - **Key references:**

    - [1] C00-20070212-127A_C.P0084 v0.88, "Physical Layer Text," 3GPP2 meeting, Seoul, February 2007.
    - [2] C00-20070212-120R1_UMB_UpperLayer_ProposedV&V, "Higher Layer Text," 3GPP2 meeting, Seoul, February 2007.
    - [3] C30-20060626-054, "Framework proposal for LBC mode of Rev C," Miyazaki City, June 2006.

Specification Structure and Style

- Approx. 1172 pages spread across 10 documents
- Includes an Overview, separate Physical Layer and MAC Layer documents, Security Functions documents and several Upper Layer documents
- All documents are Stage 3, with explicit or implicit (“shall/should/may”) language identifying mandatory and optional functionality
- Sections contain requirements on both infrastructure and access terminals
- The description of functionality is modularized, with internal entities (called “protocols”) grouped in “layers” and “planes”
- Modules are supposed to:
  - communicate with homologous modules across the air interface via “headers” and “messages”
  - communicate with other modules via “indications” and “commands”
  - store and retrieve information internally as *static* or *dynamic parameters*, and in / from a common area called “public data”
  - run as *state machines* with event-driven controlled transitions between states
  - have several simultaneous *instantiations*, consisting of active (“InUse”) and ready-to-go (“InConfiguration”) instantiations
  - be grouped in *storable* “personalities”.
- There are abstract interfaces (e.g. SAPs, primitives) defined between certain layers.

Basic Operating Principles

- System consists of a set of multi-sectored fixed transceivers (an Access Network = AN) in (generally) two-way radio communication with a set of mobile transceivers (Access Terminals = ATs)
- The ANs may or may not be synchronized with one another
- One AT may be served by multiple ANs at the same time, the AT having a separate protocol stack for each AN ("route")
- One AN may serve multiple ATs, including some with traffic arriving ("tunneled") from other ANs
- Designed such that data on inter-AN interface can be tunneled directly to the AT, i.e. operation can continue after a handoff without the need to transfer control state from the old to the new AN
- AN is able to transmit in unicast and broadcast / multicast modes
- Flexibility: AN and AT each capable of negotiating configurations
- Security: air link made secure through ciphering and integrity protection
- Increased RF efficiency: AN and AT may have multiple antennas with MIMO capability
- QoS support over the air

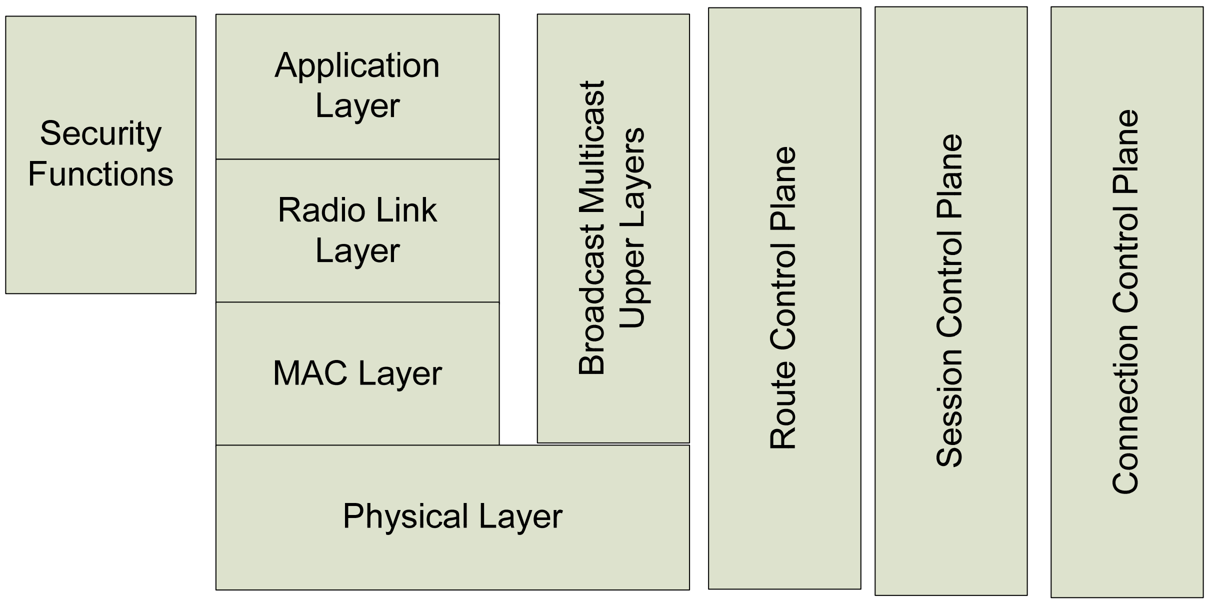
Physical layer characteristics

- Full-duplex paired spectrum with bandwidths ranging from 1.25 MHz through 20MHz; half-duplex mode also defined
- Peak data rate FL/RL: 268 Mbps / 84 Mbps
- Multi-carrier operation
- Single frequency reuse possible (through scrambling)
- OFDM technology used on both FL and RL
- The RL also allows CDMA segments
- Support for Hybrid ARQ on both FL and RL
- Optional support of Rotational OFDM
- Various modulation and encoding schemes supported
- Special processing for broadcast and multicast data and optional support of supercast of unicast data on broadcast channels
- Support for multiple effective antennas

Signaling characteristics

- Relatively light on signaling through use of:
  - Default values and configurations
  - Implicit functionality
  - Compressed identifiers through resources grouping and use of sophisticated indexing
  - Messages that are sent often tend to be very short
  - Dissemination of system and access information via broadcast channels
- Flexible and functionality-rich signaling through availability of multiple schemes and formats
- “Bootstrap”-like system acquisition
- Detailed “neighbor” sector/cell information provided
- QoS-dependent random access procedures
- Compressed paging (for efficiency)
- Automatic transitions to decayed states of connectivity based on inactivity period duration (reduces battery consumption)
- Ciphering is tightly coupled with RLP
- RoHC may be flexibly placed at the AN or “above” the AN
- RLP used for both “Control Plane” and “User Plane”
- Efficient VoIP support through group-level resource assignment

UMBFDD Protocol Architecture



Brief description of Layers and Planes

- **Physical Layer**: RF, power, modulation, encoding, scrambling, antenna management, channelization
- **MAC Layer:** procedures to transmit and receive data over the Physical Layer
- **Radio Link Layer**: QoS negotiation, multiplexing of higher layer packets and support for various delivery modes (e.g. reliable, in-sequence, etc.)
- **Application Layer:** signaling, inter-route tunneling, support functionality (e.g. RoHC, EAP) and user plane support (e.g. IP)
- **Connection Control Plane**: radio resource and connection management
- **Session Control Plane**: configuration, negotiation and address management
- **Route Control Plane**: route management
- **Security Functions:** key exchange and generation, encryption/decryption, digital signatures for integrity

UMBFDD Physical Layer

System Overview – Forward Link

- Adaptive coding and modulation with resource adaptive synchronous H-ARQ and turbo coding
  - Modulation includes: QPSK, 8PSK, 16QAM, and 64QAM
- Short HARQ retransmission latency
  - Approximately 5-7 ms on Forward and Reverse Link
- OFDMA Forward Link with MIMO and transmit diversity support
  - Single codeword MIMO with closed loop rate & rank adaptation
  - Multi-codeword (layered) MIMO with per-layer rate adaptation
  - Peak rate over 260 Mbps in 20 MHz Forward Link
  - Support for STTD
- Efficient frequency diversity and frequency selective Forward Link transmission
  - Multiplexing of DRCH and BRCH
- Forward Link precoding & SDMA
  - MISO / MIMO closed loop precoding with low-rate feedback
  - Combined precoding and space division multiple access
- Subband scheduling
  - Enhanced performance on Forward & Reverse Link
  - Multi-user diversity gains for latency sensitive traffic
- Signaling enhancements
  - Group resource allocation (GRA) for high VoIP capacity
  - Dynamic sharing of resources between data and control

System Overview – Reverse Link

- **Quasi-Orthogonal Reverse Link**
  - Orthogonal transmission based on OFDMA
  - Non-orthogonal transmission with Layer Superposed OFDMA (LS-OFDMA)
- **Pre-coded CDMA Reverse Link segment**
  - Statistical multiplexing of various Reverse Link control channels
  - Optional support for low-rate data transmissions, subject to AT capabilities
  - Fast access with reduced overhead and fast request
  - Broadband reference for power control and sub-band scheduling
  - Efficient handoff support
- **Optimized throughput / fairness tradeoff through power control**
  - Distributed power control based on other cell interference indications
- **Interference management through fractional frequency reuse**
  - Improved coverage and edge user performance
  - Dynamic fractional frequency reuse to optimize bandwidth utilization
- **Bandwidth Flexibility**
  - Scalable design with fine bandwidth granularity from 1.25 to 20 MHz

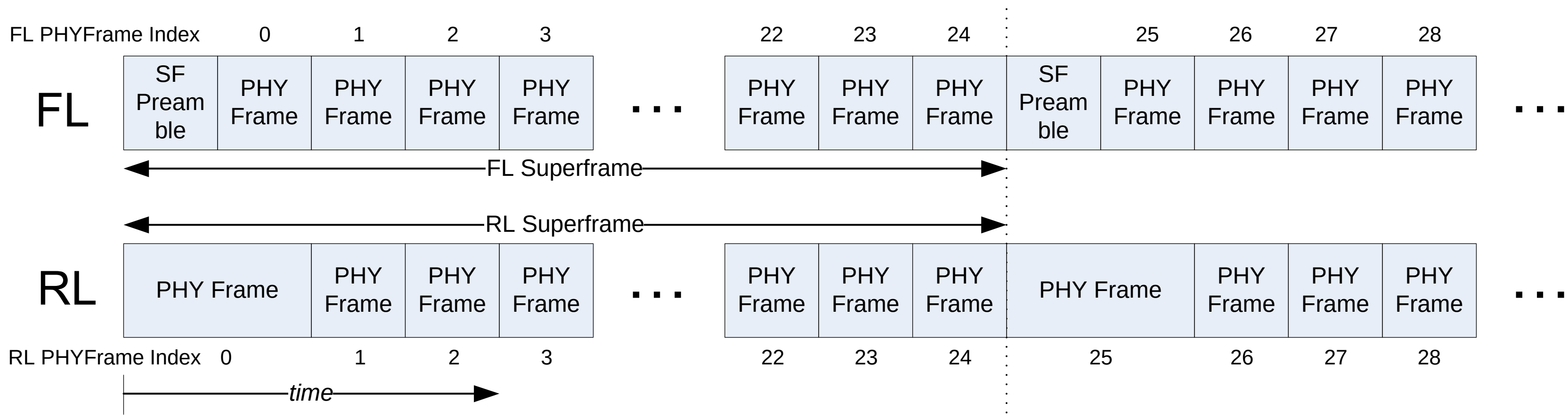
System Overview

- **Efficient handoff support**
  - support for FL softer handoff group selection to improve edge user performance
  - Support for independent switching of FL and RL serving sectors
- **Intra-cell SFN transmission to enhance FL traffic and signaling**
  - SFN transmission to softer handoff users on FL
  - SFN transmission of quick paging channel
  - SFN transmission of regular pages
- **Rotational OFDM optional for AT and AN**

OFDM System Numerology

	FFT Size					
Parameter	**NFFT = 128**	**NFFT = 256**	**NFFT = 512**	**NFFT = 1024**	**NFFT = 2048**	**Units**
Chip Rate 1/TCHIP	1.2288	2.4576	4.9152	9.8304	19.6608	Mcps
Subcarrier Spacing 1/(TCHIPNFFT)	9.6	9.6	9.6	9.6	9.6	kHz
Bandwidth of Operation	≤ 1.25	1.25–2.5	2.5–5	5–10	10–20	MHz
Cyclic Prefix Duration TCP = NCPNFFTTCHIP/16 NCP = 1, 2, 3, or 4	6.51, 13.02, 19.53, or 26.04	6.51, 13.02, 19.53, or 26.04	6.51, 13.02, 19.53, or 26.04	6.51, 13.02, 19.53, or 26.04	6.51, 13.02, 19.53, or 26.04	μs
Windowing Guard Interval TWGI = NFFTTCHIP/32	3.26	3.26	3.26	3.26	3.26	μs
OFDM Symbol Duration Ts = NFFTTCHIP(1 + NCP/16 + 1/32) NCP = 1, 2, 3, or 4	113.93, 120.44, 126.95, or 133.46	113.93, 120.44, 126.95, or 133.46	113.93, 120.44, 126.95, or 133.46	113.93, 120.44, 126.95, or 133.46	113.93, 120.44, 126.95, or 133.46	μs

Superframe Structure



- **A Superframe consist of a superframe preamble followed by 25 PHY Frames**
- **Each PHY Frame and the Superframe preamble consists of 8 OFDM symbols.**
- **First RL PHY Frame in a superframe is elongated (16 OFDM symbols) so as to align forward and reverse links.**
- **Superframe preamble carries acquisition pilots and overhead channels for initial acquisition.**
- **A guard time of 78.13 μs is inserted between PHY Frames for Half-Duplex operation.**

System Resource Management

- **Resource allocation including rate determination centralized at AP for both forward and reverse links**
  - For FL, based on FL channel quality reports from AT
  - For RL, based on measurements of RL channel quality as well as RL feedback from the AT including resource requests
  - Network assigns FL and RL resources via Shared Control Channel (F-SCCH)
  - FL resources can also be assigned with Group Resource Allocation signaling
  - CDMA traffic resource allocation is AT-centric (autonomous) once CDMA traffic zone has been allocated by the AP
- **Scheduler goals**
  - Maximize system capacity
  - Manage QoS requirements such as AT throughput and latency
  - Maintain fairness across ATs with widely disparate channel qualities
  - Design ensures that the scheduler has information required to utilize features such as sub-band scheduling, fractional frequency reuse, precoding, and SDMA to achieve the above goals
  - CDMA traffic zone transmissions allow for bursty low bit rate traffic and cell-edge users to communicate without explicitly being scheduled by AP
  - CDMA resource allocation is semi-static by the AP

Coding and Modulation

- **Rate 1/3 convolutional code for block lengths ≤ 128**
- **Rate 1/5 turbo code for block lengths > 128**
- **Code is punctured or repeated to achieve desired code rate.**
- **Synchronous HARQ on both links**
  - **Channel interleaver**
  - **Based on bit-reversal**
  - **Provides almost-regular puncture patterns and good interleaver distance properties at all code rates**
- **Packet formats**
  - **Supports the following modulation formats**
    - QPSK, 8PSK, 16QAM, 64QAM
  - **Supports wide range of spectral efficiencies.**
- **Modulation step-down**
  - **At high spectral efficiencies, later HARQ transmissions use lower order modulations**
    - this avoids repetition of coded bits
  - **Gains up to 1 dB for later transmissions**

Forward Link

Forward Link Pilot and Preamble Channels

Pilot Channels	
F-CPICH	Forward Common Pilot Channel
F-CQIPICH	Forward CQI Pilot Channel
F-DPICH	Forward Dedicated Pilot Channel
F-PPICH	Forward Preamble Pilot Channel
F-BPICH	Forward Beacon Pilot Channel
Control Channels Transmitted in the Superframe Preamble	
F-ACQCH	Forward Acquisition Channel
F-PBCCH	Forward Primary Broadcast Control Channel: Carries Deployment-Specific Parameters
F-SBCCH	Forward Secondary Broadcast Control Channel: Carries Sector-Specific Parameters
F-QPCH	Forward Quick Paging Channel
F-OSICH	Forward Other-Sector-Interference Channel: Carries an Other-Sector-Interference Indication

Forward Link Control and Traffic Channels

Control Channels Transmitted in the Control Segment of PHY Frames	
F-SCCH	Forward Shared Control Channel: Carries Access Grants, Assignment Messages, and Other Messages Related to Resource Management
F-ACKCH	Forward Acknowledgement Channel: Carries Acknowledgement Bits for the Reverse Link H-ARQ Transmissions
F-PCCH	Forward Power Control Channel: Carries Reverse Link Power Control Commands
F-PQICH	Forward Pilot Quality Indicator Channel: Carries the Strength of the Reverse Link Pilots of Each Active Terminal
F-FOSICH	Forward Fast Other-Sector-Interference Channel: Carries an Other-Sector-Interference Indication Transmitted at a Faster Rate But with Less Coverage than the F-OSICH
F-SPCH	Forward Start of Packet Channel
F-RABCH	Forward Reverse Activity Bit Channel
F-IOTCH	Forward Interference over Thermal Channel
Traffic Channel	
F-DCH	Forward Data Channel: Carries the Forward Link Data

Superframe Preamble Structure

	F-PBCCH	F-SBCCH or F-QPCH	F-SBCCH or F-QPCH	F-SBCCH or F-QPCH	F-SBCCH or F-QPCH	TDM Pilot 1 (F-ACQCH)	TDM Pilot 2 (F-OSICH)	TDM Pilot 3 (F-OSICH)
OFDM Symbol Index →	0	1	2	3	4	5	6	7

- First symbol carries the primary broadcast control channel (F-PBCCH)
- Symbols 1-4 carry
  - the secondary broadcast control channel (F-SBCCH) and the forward quick paging channel (F-QPCH) in alternate superframes.
- Last three symbols are TDM pilots for
  - Initial acquisition
  - TDM 2 & 3 carry the other-sector interference indication (F-OSICH) bit
  - TDM 1 forms the forward Acquisition Channel (F-ACQCH)

Synchronization Modes

- **Semi Synchronous mode**
  - **TDM pilots change from superframe to superframe**
  - **Different sectors use offsets of the same sequence**
  - **Requires superframe level synchronization between different sectors**
  - **Symbol/chip level synchronization not required**
    - Can be used to improve performance (reduce acquisition time, fast sector switching, interference estimation etc)
- **Asynchronous mode**
  - **TDM pilots are the same from superframe to superframe**
  - **No synchronization requirement between sectors**

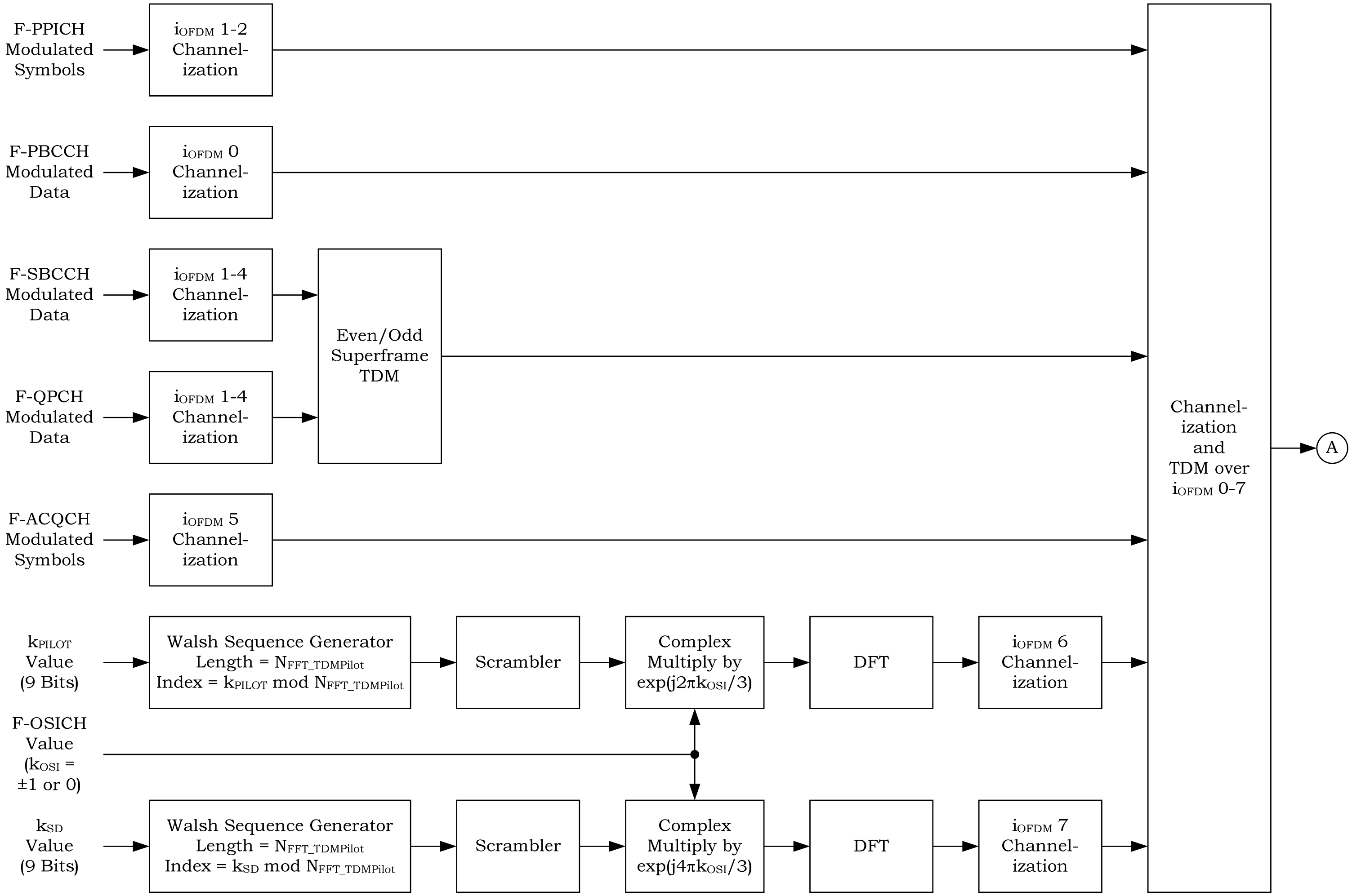
Acquisition Pilot Structure

- Three acquisition pilots: TDM1, TDM2 and TDM3
- TDM1 is used for initial timing acquisition and coarse frequency offset recovery
  - occupies one OFDM symbol
- TDM1 also carries information assisting in system determination by the AT
  - Symbol present in every fourth sub-carrier
  - Occupies available bandwidth for FFT size less than 512, and only central 480 sub-carriers for FFT sizes of 1024 and 2048
- F-OSICH is carried over TDM2 and TDM3
  - Conveys the other-sector interference indication for assisting RL interference (power) control for OFDMA data channel
  - Conveyed as different phases on the two symbols
  - TDM2,3 first defined as Walsh code in time domain, then converted to the frequency domain using DFT for OFDM modulation
  - Modulation of TDM2,3 depends on value of PilotPN in Asynchronous mode and PilotPhase in Synchronous Mode
  - Transmitted over the central 512 sub-carriers for larger than 512 FFT sizes.

Broadcast Channels

- **Superframe preamble carries channels F-PPICH, F-PBCCH and F-SBCCH**
- **F-PPICH is the preamble pilot channel**
  - Can be used for coherent demodulation of F-OSICH
  - Present only in the first two symbols of the preamble
- **F-PBCCH is the primary broadcast channel**
  - Carried in the first OFDM symbol
  - Can be put in frequency reuse mode
  - Jointly encoded over 16 superframes
  - Carries deployment-wide static parameters
- **F-SBCCH carries sufficient information to enable the AT to demodulate FL data from the PHY Frames**
  - Info on FL hopping patterns, pilot structure, control channel structure, transmit antennas, multiplexing modes etc
  - This info is transmitted every alternate superframe; other superframes used to carry pages (F-QPCH)
- **F-QPCH (Quick Paging Channel)**
  - Carried in the even superframes on symbol indices 1-4.
  - Packet encoded over a single superframe
  - Modulation depends on whether frequency reuse is enabled or not
  - Multiple F-QPCH packets can be transmitted if expanded QPCH is enabled
- **These channels enable a flexible physical layer**
  - Can configure cyclic prefix, number of antennas, pilot structure, etc
  - Support FL and RL control channels with flexible overheads, which can be matched to the current user loads
  - Can enable or disable features like sub-band scheduling, FFR etc

Superframe Preamble Modulation



Note: i_{OFDM} is the superframe OFDM symbol index.

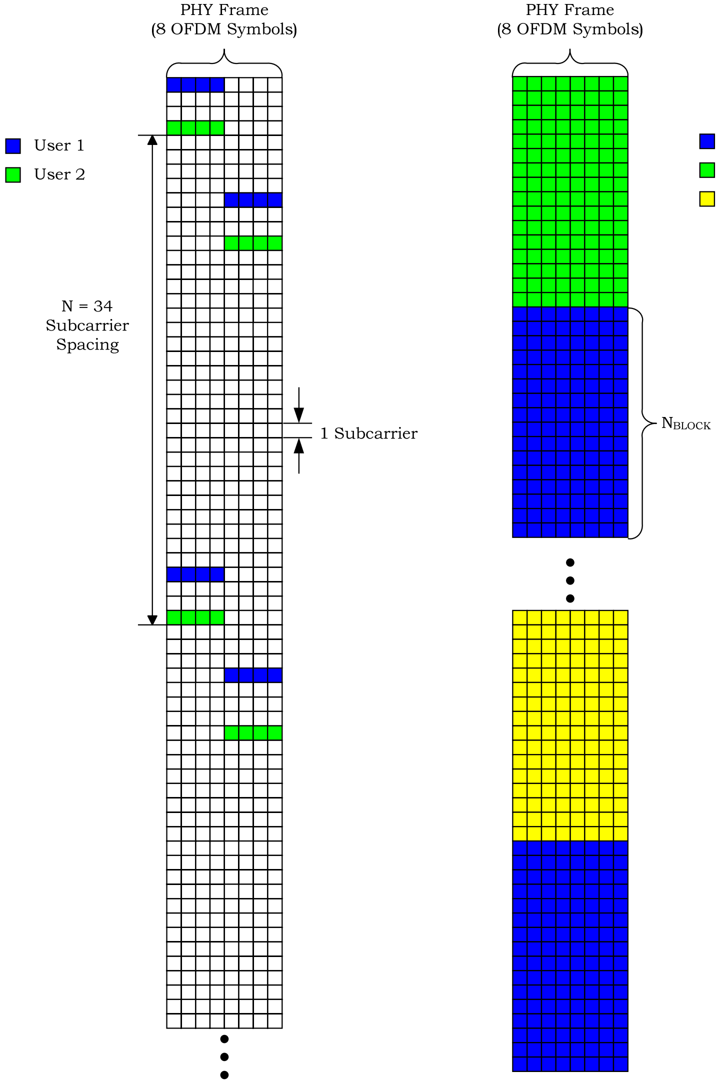
Forward Link Channelization

- **Two types of assignments**
  - **Distributed Resource Channel (DRCH)**
    - Set of tones scattered across entire bandwidth
    - Hop permutation maps assign hop ports to frequency
    - Hop permutation changes every OFDM symbol
    - Channel and interference estimation based on broadband common pilot
  - **Block Resource Channel (BRCH)**
    - Set of tiles scattered across entire bandwidth
      - one tile consists of 8 contiguous OFDM symbols and 16 contiguous tones
    - Hop permutation maps assign hop ports to tiles in frequency; fixed for duration of PHY Frame
    - Independent hopping across sectors
    - Localized channel and interference estimation over every tile based on a dedicated pilot

Multiplexing of DRCH and Block Hopping

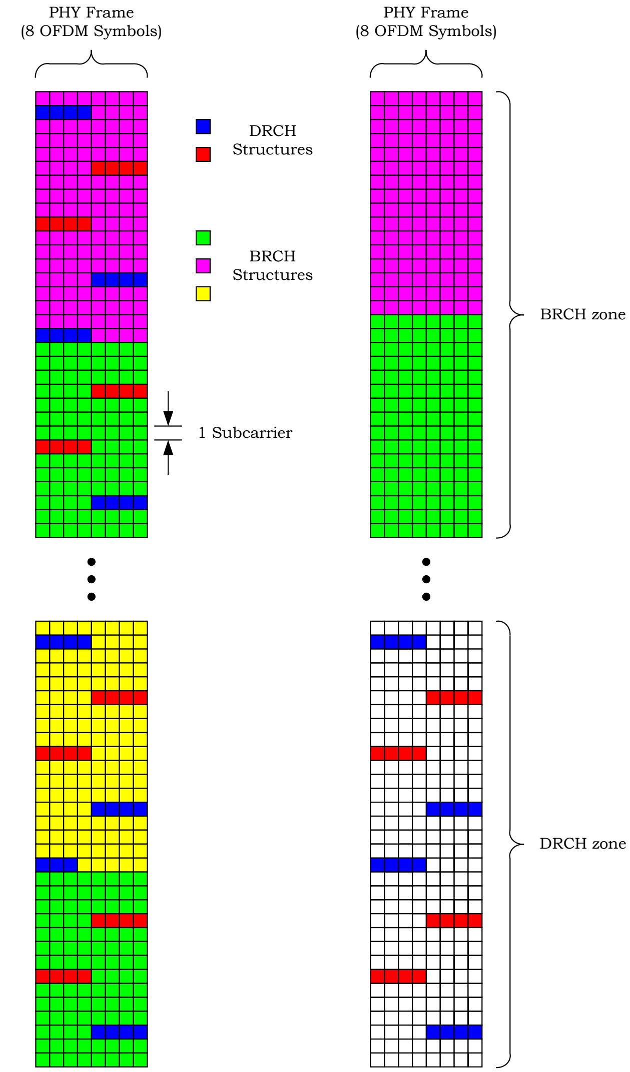
- DRCH and BRCH assignments coexist in the same PHY Frame
- Two modes for multiplexing these types of assignments
- Mode 1: DRCH punctures BRCH
  - Overhead channel indicates how many DRCHs are used so that ATs know the puncturing pattern
  - Common pilot is used over entire band
    - Common and auxiliary pilot distributed on tones both in frequency and time domain
    - Common and auxiliary pilots are time and frequency multiplexed
- Mode 2: DRCH and BRCH are only used on different sub-zones
  - Overhead channel indicates which sub-zones are in DRCH and which subbands are in BRCH.
  - Common pilot is used for DRCH sub-zone
    - Common and auxiliary pilot placed on distributed tones both in frequency and time domain
  - Dedicated pilot is used for BRCH sub-zone

DRCH and BRCH Structures and Multiplexing



(a) DRCH structure

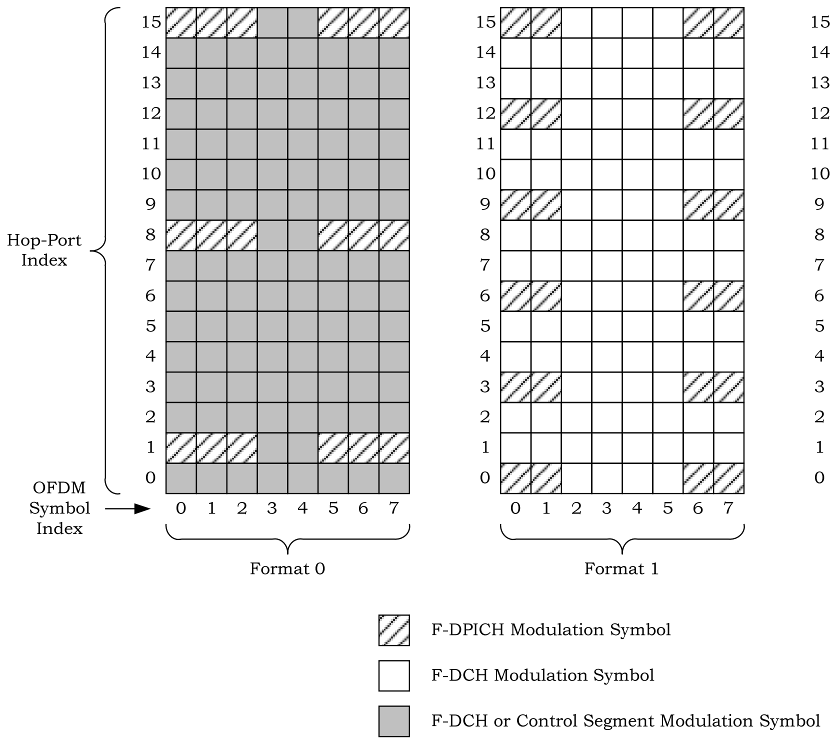
(b) BRCH structure



(a) Multiplexing Mode 1

(b) Multiplexing Mode 2

BRCH Tile Definition



- **Pilot patterns**
  - Enough pilot positions to capture time & frequency selectivity
  - MIMO support → orthogonal overlapped pilot sequences over each contiguous pilot cluster
  - Three patterns trade-off pilot overhead with support for MIMO and high delay spread channels
  - Pilot pattern indicated through packet format
- **Pilots and data symbols within block undergo the same transmit processing**
- **Pilot overhead (identical for SIMO and MIMO)**
- **Efficient support for**
  - Advanced multi-antenna techniques: MIMO, precoding, SDMA
  - Interference estimation and spatial interference nulling

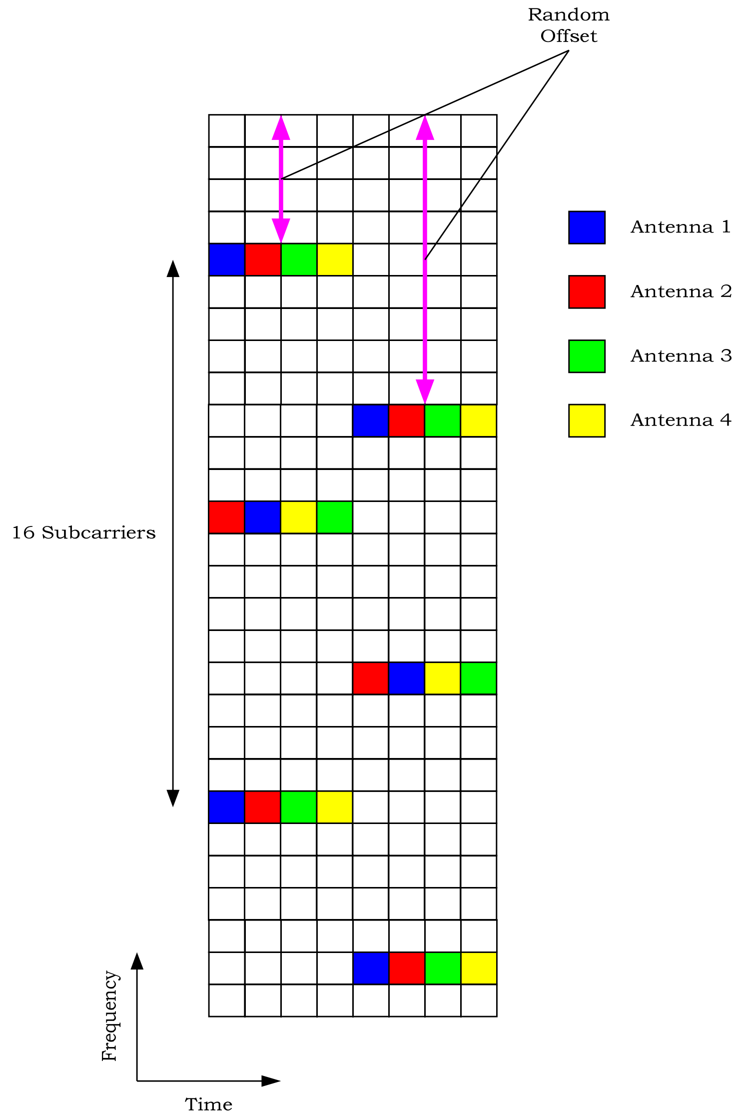
Forward Link Packet Formats

Packet Format Index	Spectral efficiency on 1st trans-mission	Modulation order for each transmission					
		1	2	3	4	5	6+
0	0.33	2	2	2	2	2	2
1	0.67	2	2	2	2	2	2
2	0.94	2	2	2	2	2	2
3	1.5	4	3	3	3	3	3
4	2.0	4	3	3	3	3	3
5	2.5	6	4	4	3	3	3
6	3.0	6	4	4	4	4	4
7	3.5	6	4	4	4	4	4
8	4.0	6	6	4	4	4	4
9	4.5	6	6	4	4	4	4
10	5.0	6	6	4	4	4	4
11	6.0	6	6	4	4	4	4
12	7.0	6	6	6	4	4	4
13	8.0	6	6	6	4	4	4
14	9.5	6	6	6	6	4	4
15	NULL						

FL Pilot Channels

- **F-CPICH: Common Pilot**
  - Present in both MuxMode 1 and MuxMode 2
  - Is the only pilot used in MuxMode 1 and is a wideband pilot
  - Used for channel estimation and CQI estimation in MuxMode 1
  - In MuxMode 2, F-CPICH is present only in DRCH sub-zones
- **F-DPICH: Dedicated Pilot**
  - Present only in MuxMode 2, and transmitted in the BRCH sub-zones
  - Used for tile-based channel estimation for BRCH sub-zone tiles
- **F-CQIPICH: CQI Estimation Pilot**
  - Used only in MuxMode 2, for CQI estimation
  - Low overhead, transmitted once every 8 PHY Frames

FL Pilot Channels



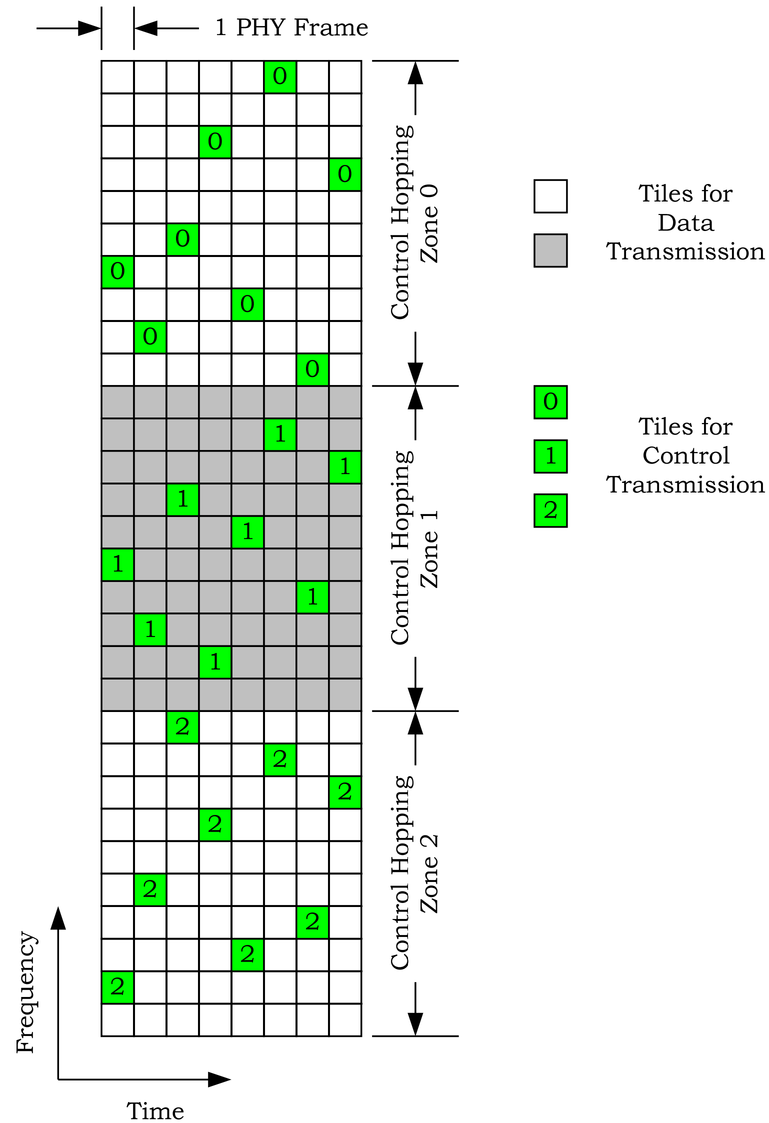
Example of F-CPICH when NumPilotAntennas = 4

FL Pilot Channels

- **Forward Cell Null Channel (F-CNCH)**
  - Defines sub-carriers that are blanked by all the sectors in a cell
  - Used to measure out-of-cell interference level
- **Forward Beacon Pilot Channel (F-BPICH)**
  - Used to indicate to the AT, the presence of an AN on other carriers
  - Two beacon codes defined based on Reed-Solomon codes
  - Number of symbols (equal to number of carriers) are reserved for beacon transmission every two superframes
  - No other channel is transmitted on the carrier carrying a beacon pilot on the corresponding beacon pilot symbol

FL Control Channels

- **Control segment allocation**
  - All FL control channels multiplexed together onto a set of FL control segment (FLCS) hop ports
  - FLCS ports can be either all BRCH or all DRCH
  - Sub-carriers used by pilot channels or beacon channels cannot be used by FLCS ports

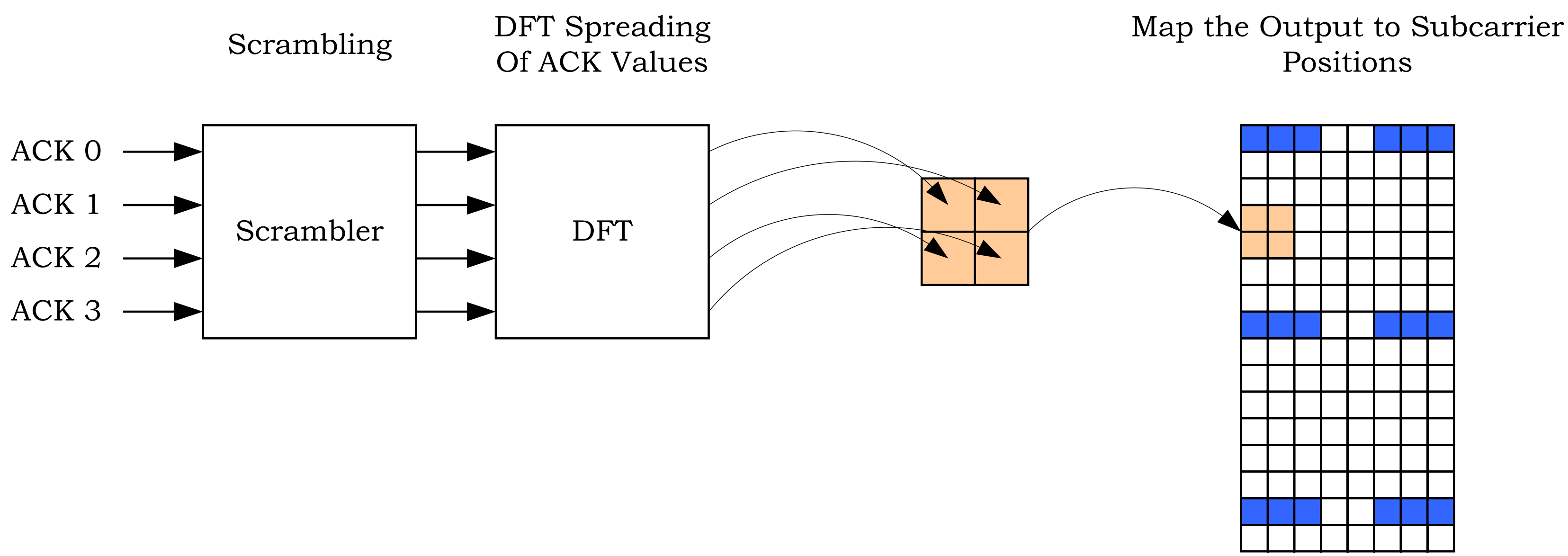


FL Control Channels

- Forward Start of Packet Channel (F-SPCH)
  - Used to indicate if a persistent assignment is still valid
- Forward Reverse Activity Bit Channel (F-RABCH)
  - One bit indication of the load on the RL CDMA segment
  - Sequence of 4 bits encoded by rate 1/3 concatenated code and QPSK scrambled
- Forward Pilot Quality Indicator Channel (F-PQICH)
  - Carries quantized values of RL pilot strength for each AT
  - Aids the AT in determining best RL serving sector
  - Used to power control RL control and data channels
  - Encoded by rate 1/3 concatenated code and QPSK scrambled
- Forward Fast Other Sector Interference Channel (F-FOSICH)
  - Used for fast indications of interference levels
  - Encoded by rate 1/3 concatenated code and QPSK scrambled
- Forward Interference Over Thermal Channel (F-IOTCH)
  - Used for indications of interference levels on a given sub-band
  - Encoded by rate 1/3 concatenated code and QPSK scrambled
- Forward Power Control Channel (F-PCCH)
  - One bit up/down power control command for RL CDMA control channel transmit power

FL Control Channels

- **Forward Acknowledgement Channel (F-ACKCH)**
  - **Used to acknowledge RL HARQ transmissions**
  - **Present in every PHY Frame**
  - **Spread with a DFT matrix if using a BRCH resource, and an Identity matrix for a DRCH resource**
  - **Third order diversity achieved**



FL Control Channels

- **Forward Shared Control Channel (F-SCCH)**
  - **Carries a set of encoded and CRC protected blocks for assignments**
  - **(F/R)LAB = Forward/Reverse Link Assignment Block**
    - Sends assignment to a user, indicating the physical resources assigned (subcarriers) and the modulation/coding/pilot structure for use
    - Both persistent and non-persistent assignments supported
    - Supplemental assignments supported
    - Support for Resource Adaptive HARQ – reassignment of resources during a continuing packet transmission
  - **Access Grant Block**
    - Transmitted in response to (and scrambled by) a detected access sequence
    - Provides a user with fine RL timing, a MACID to identify the user, and an initial channel assignment
  - **MIMO Assignment Blocks**
    - Assign resources to MIMO users
    - Supports single codeword MIMO assignments providing packet format and the number of layers to transmit
    - Support multi-codeword MIMO assignments: provides independent packet format per codeword

Coding and Modulation

Forward Preamble Pilot Channel	None
Forward Primary Broadcast Control Channel	Rate-1/3 Convolutional
Forward Secondary Broadcast Control Channel	Rate-1/3 Convolutional
Forward Acquisition Channel	None
Forward Beacon Pilot Channel	None
Forward Quick Paging Channel	Rate-1/3 Convolutional
Forward Other-Sector-Interference Channel	None
Forward Common Pilot Channel	None
Forward Channel Quality Indicator Pilot Channel	None
Forward Dedicated Pilot Channel	None
Forward Acknowledgement Channel	None
Forward Start-of-Packet Channel	None

Forward Shared Control Channel	Rate-1/3 Convolutional
Forward Pilot Quality Indicator Channel	Rate-1/3 Concatenated
Forward Fast Other-Sector-Interference Channel	Rate-1/3 Concatenated
Forward Reverse Activity Bit Channel	Rate-1/3 Concatenated
Forward Fast Interference-over-Thermal Channel	Rate-1/3 Concatenated
Forward Power Control Channel	None
Forward Reverse Activity Bit Channel	Rate-1/3 Concatenated
Forward Data Channel	Rate-1/3 Convolutional or Rate-1/5 Turbo

MIMO Design

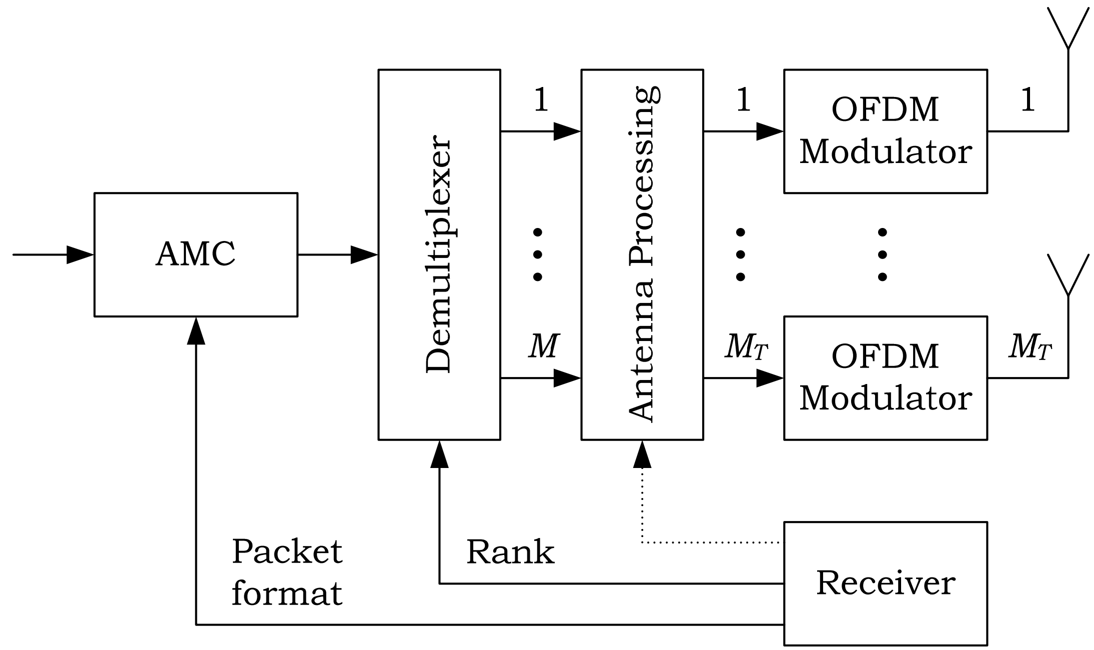
- **Complete OFDMA/MIMO design taking in consideration the following:**
  - **HARQ**
  - **Rate prediction**
  - **Channel estimation**
  - **Feedback overhead**
  - **Spatial correlation effects**
  - **MIMO complexity**
  - **Mobility**
    - *Graceful degradation at very high speeds*
  - **Simultaneously support both SISO and MIMO users**

MIMO Capabilities

- Support for
  - Closed-loop MIMO with precoding (SU-MIMO)
  - Transmit Diversity
  - SDMA (MU-MIMO)
  - Feedback channels to support the operations above.
- AT can have different capability classes to support MIMO
  - Not support MIMO (possibly support receiver diversity)
  - Support 2xN or 4xN precoding MIMO
  - Support single code word (SCW) or multiple code word (MCW)
- Transmit Diversity
  - 2-Tx STTD shall be supported by ATs capable of 2XN MIMO.
  - 4-Tx STTD shall be supported by ATs capable of 4XN MIMO.
  - 2-Tx and 4-Tx STTD can also be supported by other non-MIMO ATs, depending on AT's capabilities

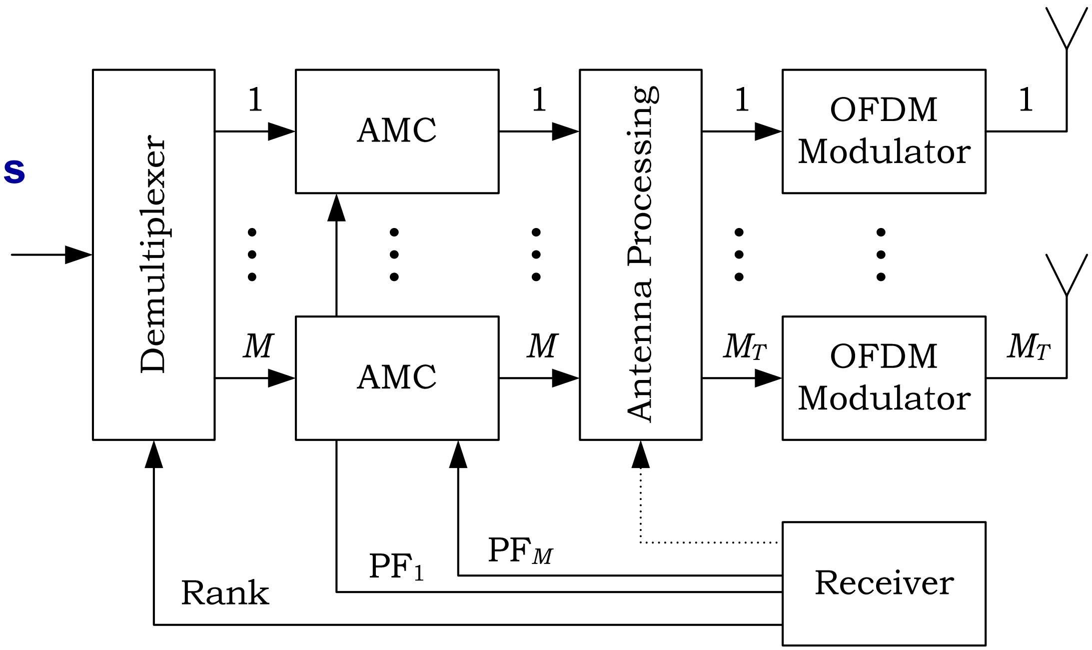
Single Code Word (SCW)

- Adapting the rate and rank to channel realizations
- One PF is transmitted with *M* modulation symbols transmitted at a time
- H-ARQ similar to SISO
- Receiver can employ a linear MMSE or more sophisticated detectors
- Low complexity if just linear MMSE is employed



Multi-Code Word (MCW)

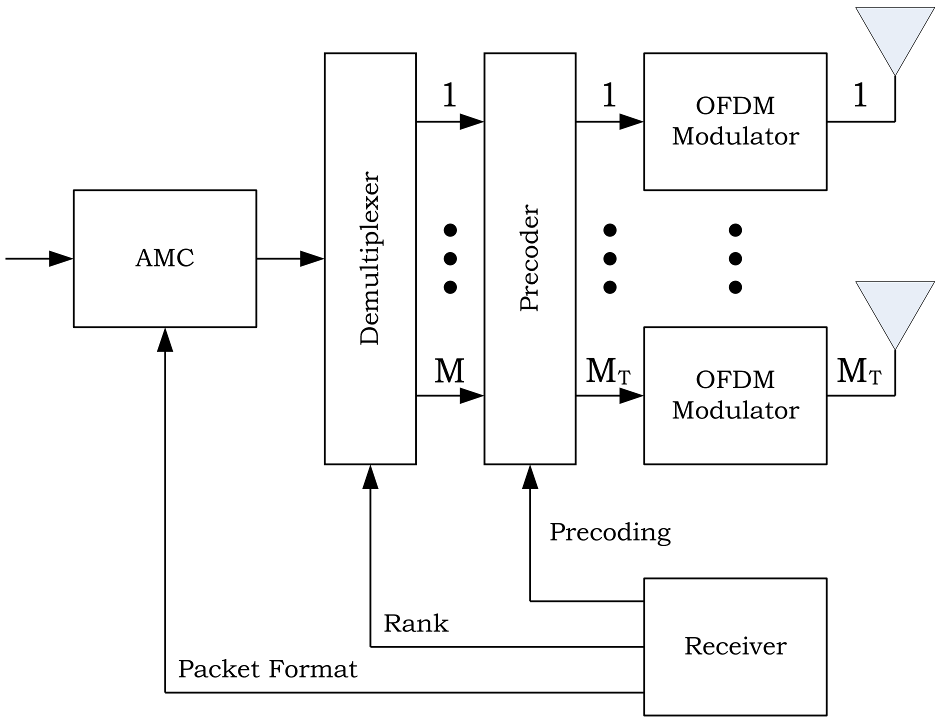
- **CQI feedback for each layer, i.e., rate prediction is done per layer**
- ***M* PFs are simultaneously transmitted**
- **SIC receiver is used to decouple the *M* layers**
- **Within the maximum number of HARQ transmissions, no new packets are transmitted on the decoded layers. Total power is equally divided on the outstanding layers**



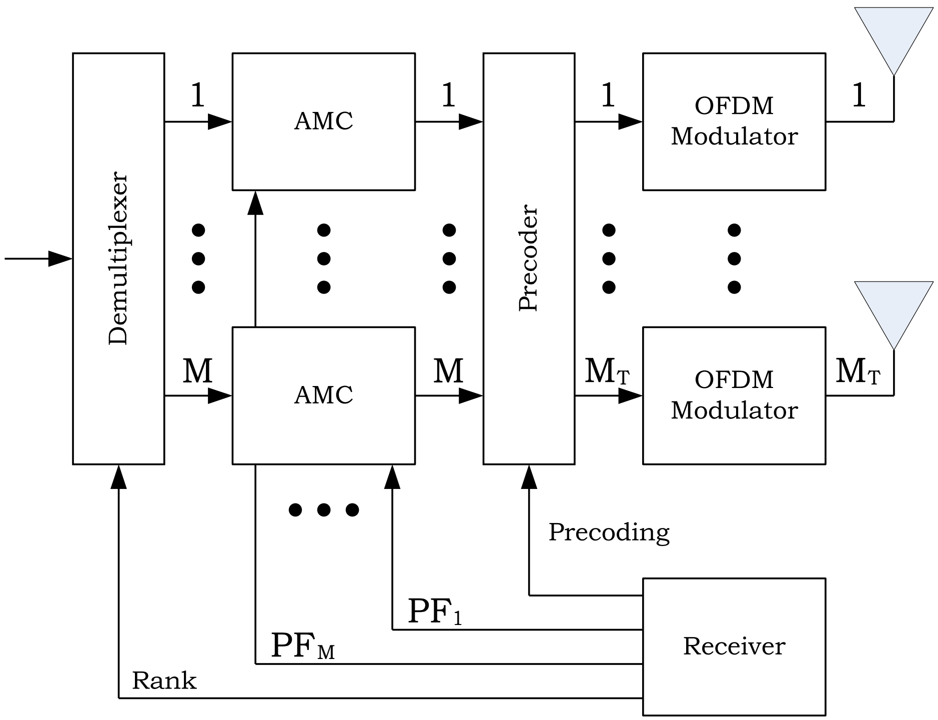
Compared to SCW/MMSE:

- more complex and memory demanding
- higher throughput and more tolerant to spatial correlation

MIMO Precoding

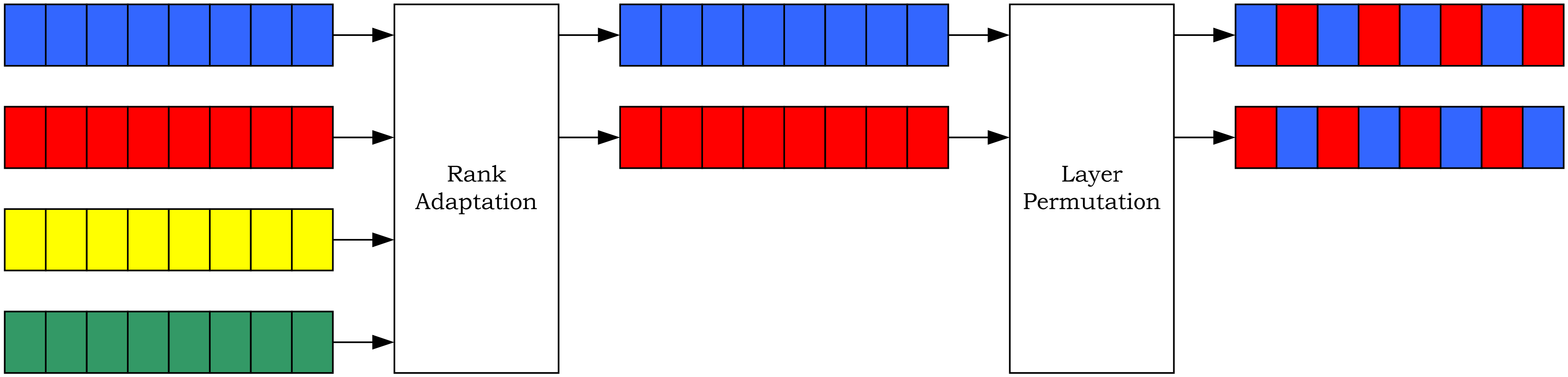


SCW MIMO Transmitter with Precoding



MCW MIMO Transmitter with Precoding

MIMO Layer Permutation



Precoding & Space Division Multiple Access

- Precoding can be used in antenna processing, which is a linear pre-processing that enables transmit beamforming
  - Beamforming gain to SIMO users
  - Eigenbeamforming gain to MIMO users
- Closed loop precoding in FDD systems is performed based on feedback from ATs.
- Space division multiple access (SDMA)
  - Multiple users scheduled on same time-frequency resource
  - Users overlapped using beams pointing in different (orthogonal) directions
  - Increased system dimension; adaptive sectorization gain
- Multiple types of precoders allowed
  - Binary unitary codebook, Fourier-based codebook, Readymade codebook and also Downloadable codebook

Feedback channels for MIMO support

Logical channels	Feedback information	# of bits
r-bfch	Precoder index	6 bits
	Delta CQI between SU-MIMO and MU-MIMO	2 bits
r-sfch	Subband delta CQI	4 bits
	Subband index	4 bits
r-mqich (SCW)	SCW MIMO CQI	5 bits
	Rank	2 bits
r-mqich (MCW)	2 per-layer CQI	8 bit

MAC Support for MIMO/SDMA

- **Requirements**
  - Support for precoding with and without SDMA
  - Scalability with high granularity in resource allocation to modes
- **Tree design**
  - Channel tree contains multiple sub-trees
  - One sub-tree per SDMA cluster with one primary sub-tree
  - Identical hop pattern across sub-trees
- **Scheduling**
  - Any user scheduled on only one sub-tree
  - Users scheduled across different sub-trees overlap
  - Users scheduled within a sub-tree remain orthogonal

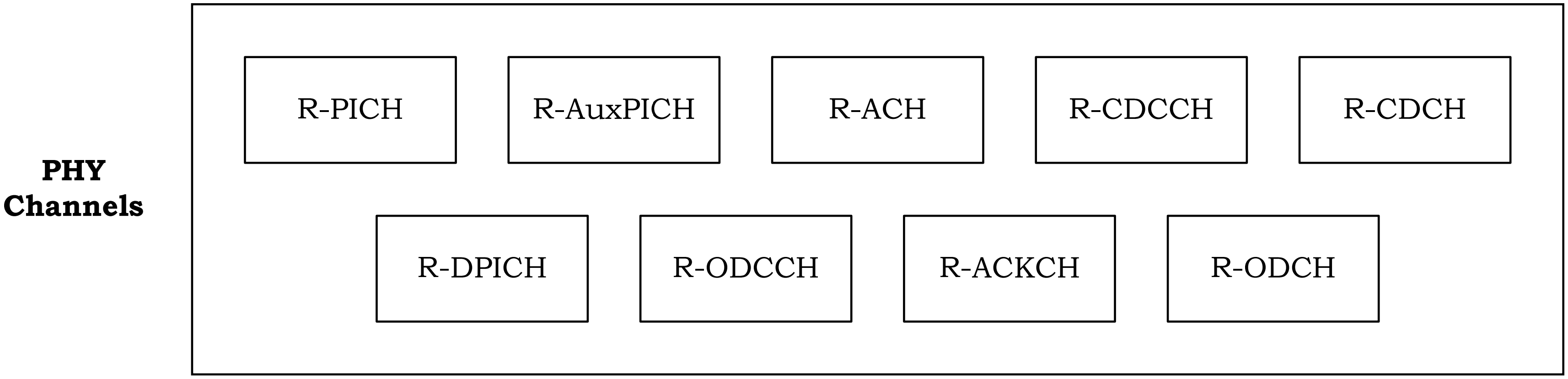
Rotational OFDM

- D contiguous modulation symbols are rotated using a rotational matrix prior to IFFT operation
- Used only in DRCH mode
- Optional for both AT and AN

Packet Format Index	Optimal Angle	
	First Transmission	Second Transmission
0	0	0
1	0	0
2	$0.4 \times \pi/4$	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	$0.3 \times \pi/4$	0
9	$0.7 \times \pi/4$	0
10	0	0
11	0	0
12	$0.2 \times \pi/4$	$0.2 \times \pi/4$
13	$0.3 \times \pi/4$	$0.3 \times \pi/4$
14	$0.4 \times \pi/4$	$0.4 \times \pi/4$
15	0	0

Reverse Link

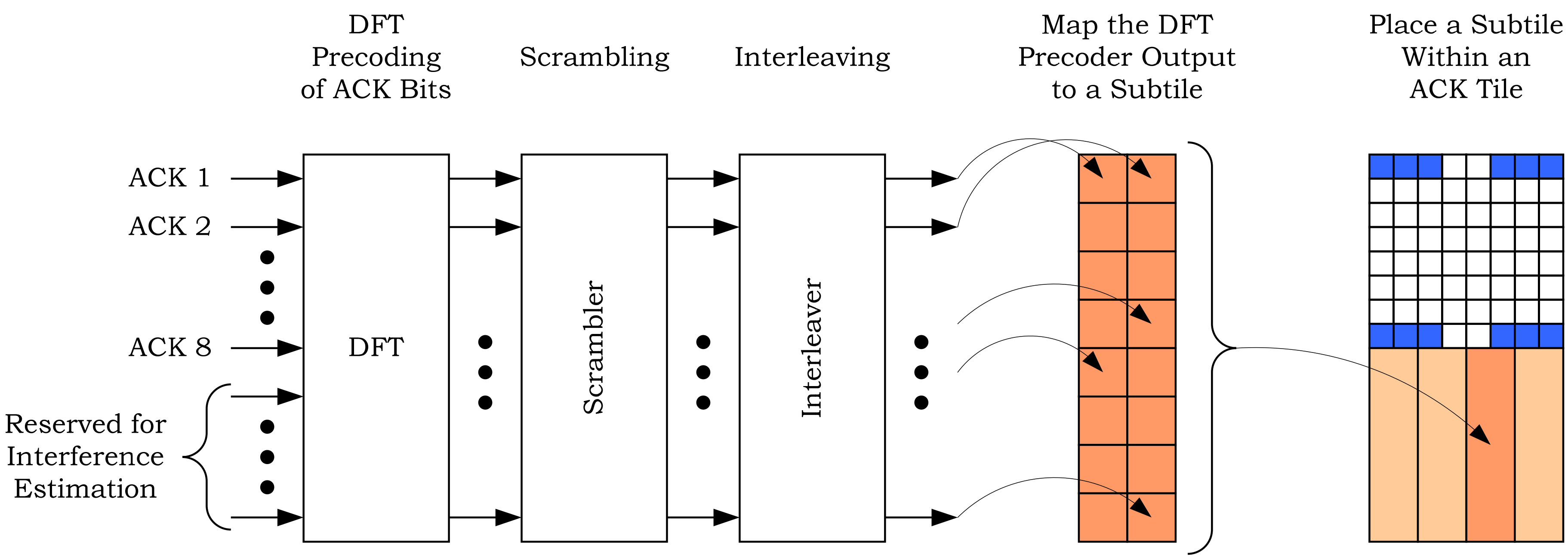
Reverse Link Channels



R-CDCCH – Reverse CDMA Control Channel
R-ODCCH – Reverse OFDMA Control Channel
R-PICH – Reverse Link broadband pilot channel
R-AuxPICH - Demodulation pilot for CDMA Data channel
R-DPICH - Demodulation tile pilot for OFDMA Data
R-ACKCH – Reverse Link acknowledgement for FL Data
R-ACH – Reverse Link access channel
R-ODCH – Reverse Link OFDMA Data channel
R-CDCH - Reverse Link CDMA Data Channel

- **R-CDCCH and R-ODCCH carry:**
  - **r-reqch** - requests Reverse Link resources
  - **r-bfch** – feedback channel in support of Forward Link precoding and SDMA
  - **r-sfch** – feedback channel in support of Forward Link subband scheduling
  - **r-cqich** – Forward Link channel quality indicator channel
  - **r-mqich** – MIMO quality indicator channel
  - **r-psdch** – PSD indicator channel
  - **r-pahch** – PA headroom indicator

RL Control Channels: R-ACK Channel Modulation



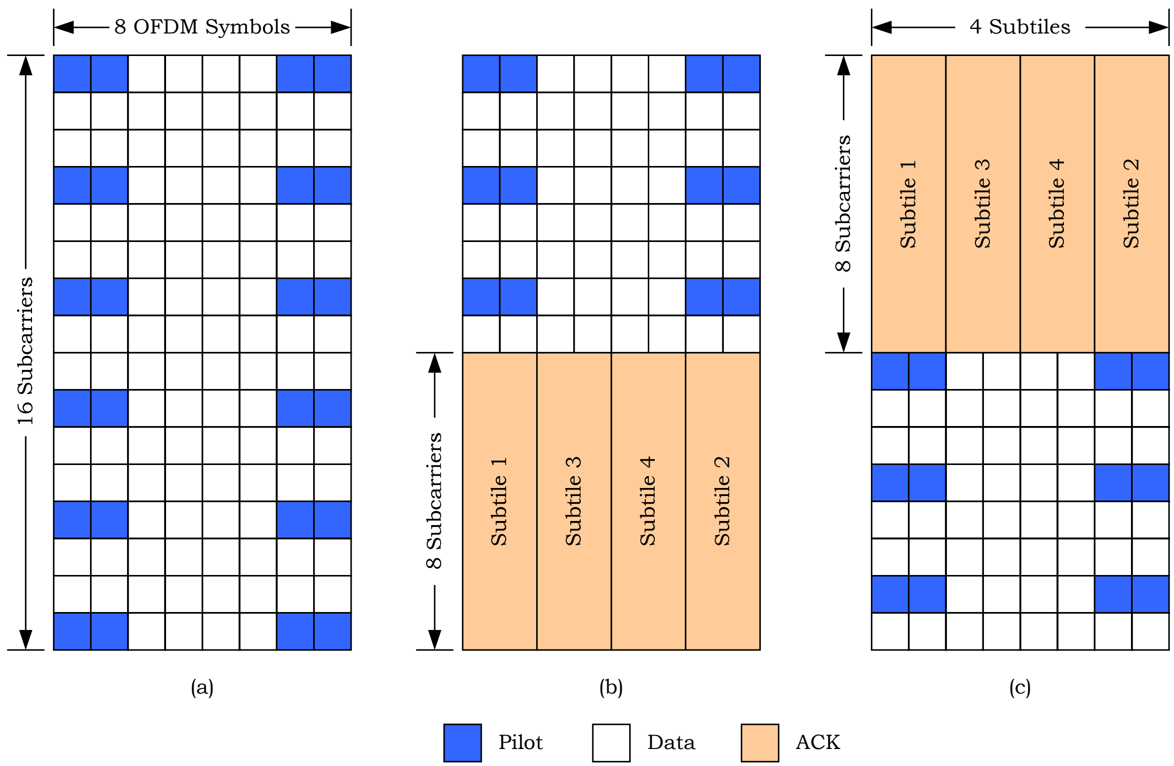
Reverse Link Data Transmission Overview

- **OFDMA and CDMA data is frequency multiplexed**
  - **Split of CDMA and OFDMA capacity is configurable by the RAN and is sector and AT specific.**
  - **Both CDMA and OFDMA traffic are power controlled**
    - CDMA power is controlled to maintain target SINR at serving sector
    - OFDMA power (PSD) is controlled to maintain desired other-cell Interference constraint
- **Multiplexing of CDMA and OFDMA traffic**
  - **RL CDMA Data Channel (R-CDCH)**
    - Used for the transmission of low-rate bursty delay-sensitive services (e.g. VoIP, Gaming etc).
    - Supports a limited set of transmission formats.
    - Support for frequency-domain interference cancellation.
    - Is supported by fast power control and HARQ and slow distributed scheduling.
  - **RL OFDMA Data Channel (R-ODCH)**
    - Fully scheduled
    - Support for quasi-orthogonal multiple antenna operation (QORL) and layered superposed OFDMA (LS-OFDMA)

Reverse Link OFDMA Packet Formats

Packet format index	Spectral efficiency on 1st transmission	Reference (Nominal) DataCtoI in dB	Modulation order for each transmission					
			1	2	3	4	5	6+
0	0.36	-1	2	2	2	2	2	2
1	0.71	1	2	2	2	2	2	2
2	1.07	2	2	2	2	2	2	2
3	1.4	4	3	2	2	2	2	2
4	1.8	5	4	3	3	3	3	3
5	2.13	7.5	6	4	4	4	4	4
6	2.5	7.5	6	4	4	4	4	4
7	3.0	8.5	6	4	4	4	4	4
8	3.5	10	6	4	4	4	4	4
9	4.0	10.5	6	6	4	4	4	4
10	4.5	11.5	6	6	4	4	4	4
11	5.0	13	6	6	4	4	4	4
12	6.0	14	6	6	4	4	4	4
13	7.0	16	6	6	6	4	4	4
14	8.0	17	6	6	6	4	4	4
15	NULL							

Reverse Link OFDMA Data Tile

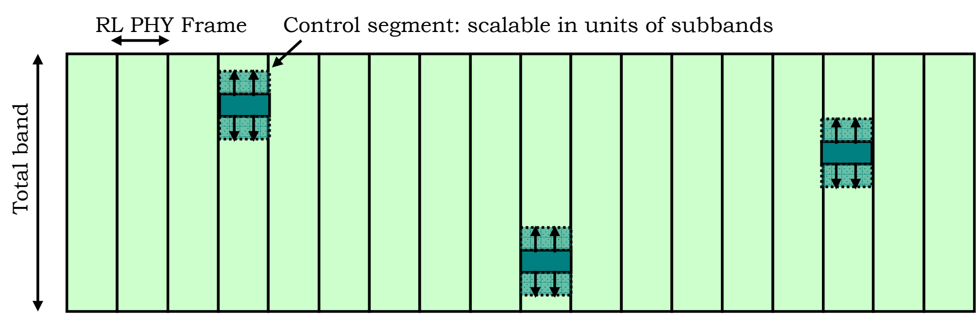


R-DPICH Format 1

- **Pilot patterns**
  - **Patterns contain enough "looks" to capture time & frequency selectivity**
  - **QORL and LS-OFDMA support → orthogonal overlapped pilot sequences over each contiguous pilot cluster**
  - **Two patterns trade-off pilot overhead with support for QORL and LS-OFDMA and high delay spread channels**
  - **Pilot pattern indicated through packet format**
  - **Pilots and data symbols within every block undergo the same TX processing**
- **Pilot overhead**
  - **Format 0 → 14.06 %; Format 1 → 18.75 %**

CDMA Control Segment

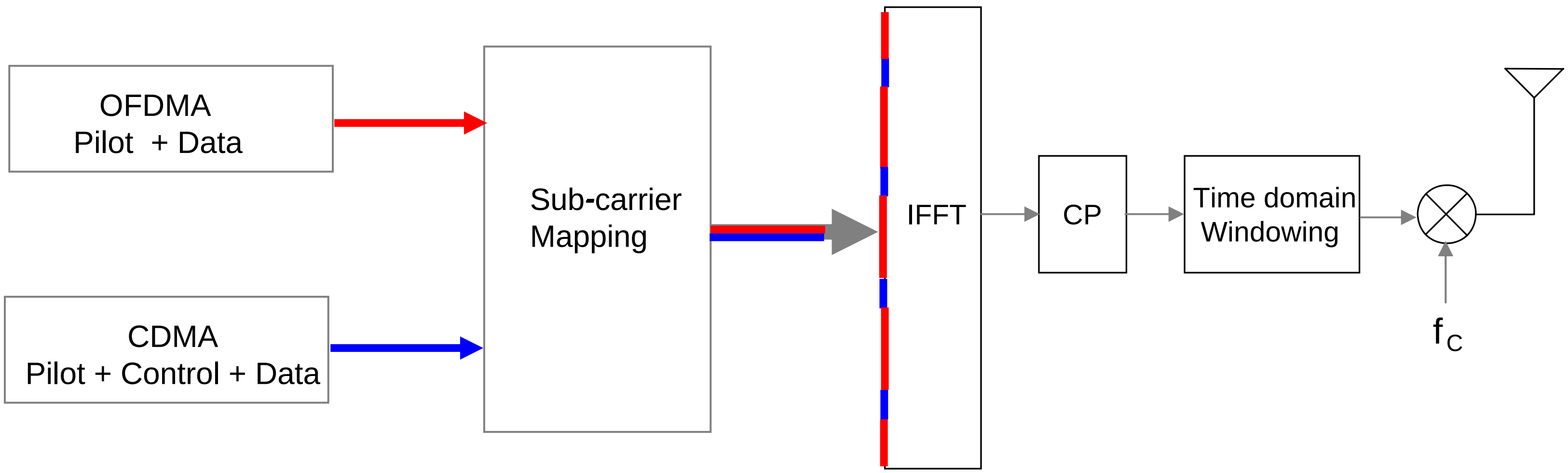
- **CDMA control segment gives statistical multiplexing of various control channels**
  - **Flexible load control by changing persistence of different channels**
  - **Overhead reduction for access channel**
  - **Broadband pilot to support subband scheduling**
  - **Fast cell switching through handoff signaling**
- **Control segment spans a number of subbands over one or more RL interlaces**
  - **Minimum assignment of 128 sub-carriers (1/4 overhead in 5MHz)**
  - **Scalable in units of subbands (1/4 granularity in 5MHz)**
- **Control segment hopping in time**
  - **R-CQICH provides power control reference across the entire bandwidth**
  - **R-CQICH and R-PICH provide broadband pilot that covers all the bandwidth over time**
- **Modulation**
  - **All channels of the control segment use Walsh codes (up to 1024)**
  - **Sector specific and, when applicable, MACID specific scrambling**



Reverse Link CDMA Data

- **Support for CDMA Traffic on the reverse link is optional for the AT**
- **AT is assigned a CDMA control sub-segment and may be assigned one or more CDMA traffic sub-segments**
  - **CDMA segment at each AP consists of multiple sub-segments, configured by the network**
  - **If an AT supports CDMA traffic, AN can assign any subset of these CDMA sub-segments to the AT for data transmission**
  - **Full flexibility of CDMA sub-segment assignment – can be common across the RAN and same for all ATs, or allow for partial overlap across APs**
    - It is also allowed to have control sub-segments only (i.e., no traffic) for all ATs
  - **Auxiliary pilots are transmitted in frames carrying data transmissions**
    - Occupy the same bandwidth as the data transmission
    - Auxiliary pilot can also be used for control channel demodulation on frames where data is transmitted
  - **Control sub-segment hops over traffic sub-segments**
- **Packet formats on CDMA traffic segment are optimized for VoIP with an EVRC vocoder**
  - **Requires three packet formats**
  - **Other types of flows may be transmitted on this segment subject to packet format limitation**
  - **CDMA flow-mapping is determined by AT using a distributed AT-centric CDMA MAC**
    - AN will indicate which flows are allowed on the CDMA traffic segment only, OFDMA traffic segment only, or both

Multiplexing of CDMA and OFDMA



Coding and Modulation

Channel	Type of Coding
Reverse Pilot Channel	None
Reverse Auxliliary Pilot Channel	None
Reverse Access Channel	None
Reverse CDMA Dedicated Control Channel	None
Reverse CDMA Data Channel	Rate-1/5 Turbo or Rate-1/3 Convolutional
Reverse Dedicated Pilot Channel	None
Reverse OFDMA Dedicated Control Channel	Rate-1/3 Convolutional
Reverse Acknowledgment Channel	None
Reverse OFDMA Data Channel	Rate-1/5 Turbo or Rate-1/3 Convolutional

Reverse Link Power Control Overview

- **RL Control Channel Power Control**
  - Fast closed loop power control is used to set the transmit power level on the reverse link control channels that are transmitted periodically
- **RL Traffic Channel Power Control: CDMA Data**
  - The traffic channel power level is set at an offset relative to R-PICH
  - The offset is based on traffic channel performance
- **RL Traffic Channel Power Control: OFDMA Data**
  - The traffic channel power spectral density (PSD) level is set at an offset relative to the control channel PSD level
  - This offset is adjusted based on interference indications received from neighboring sectors
  - Maximum traffic PSD offset limited by inter-carrier interference

RL Power Control: CDMA / OFDMA Control Channels and CDMA Data Channels

- Fast closed loop power control is used to set the transmit PSD levels on the Reverse Link CDMA control channels and data channel
- Low-power Reverse Link pilot channel (R-PICH) level is used as a common reference for power control
- Fast Power Control commands control the level R-PICH
- Outer loop may be used by the RLSS to adjust R-PICH set-point
- CDMA control channels: offset relative R-PICH
  - RoT reports used to adjust power level
  - Open loop adjustment for reverse link CDMA control channels based on RL channel quality (F-PQICH) report and RoT report by AN
  - Disjoint links may be disabled by the AN (on a per AT-basis)
- CDMA data channel: offset relative to R-PICH
  - Adjusted based on Ack/Nack reports
- R-ACKCH: offset relative R-PICH
  - IoT report by AN and F-PQICH report used to adjust PSD level
  - Open loop adjustment based on F-PQICH report and IoT report by AN

Reverse Link Power Control: OFDMA Traffic

- **OFDMA Data Channel Power Control: the traffic channel level is offset relative to the control channel level**
  - **Minimum offset based on F-PQICH and IoT reports by AN to target certain QoS driven C/I level**
  - **Maximum offset based on F-PQICH and IoT reports by AN to limit the amount of inter-carrier interference**
  - **Boost may apply in case of late H-ARQ terminations**
- **Data is transmitted at Δ dB above control**
  - **[Δ_{min}, Δ_{max}] range is chosen to satisfy ICI margin requirement**
  - **Users report highest possible Δ subject to inter-sector interference constraint**
  - **Two possible distributed algorithms for updating Δ based on OSI indications from other cells**
    - Stochastic power control
    - Deterministic power control
  - **AN can assign any Δ within user-reported maximum allowed Δ**
- **Each sector measures other sector interference and broadcasts an indication over F-OSICH**
  - **Transmitted once every superframe**
- **Fast OSI transmitted (F-OSICH) for finer adjustments to the Δ**
  - **Reacts to sudden changes of loading**
  - **Penetration is not as much as that of F-OSICH**
- **AT adjusts its Δ based on F-OSICH from nearby ANs**
- **Delta-based power control results in**
  - **high Δ for strong users**
  - **low Δ for weak users**

L1/L2 Handoff

- **AT constantly monitors Forward and Reverse channel quality of sectors within AT's active set**
  - **Acquisition pilot (F-ACQCH) / FL broadband pilot (F-CPICH) for FL quality**
  - **Reverse pilot quality report (F-PQICH) for RL quality**
- **Forward Link and Reverse Link serving sectors need not be the same**
  - **Select the strongest FL sector with adequate RL quality to close RL control**
    - use F-PQICH report by AN
  - **Select the strongest RL sector with adequate C/I to meet QoS requirements**
    - use IOT reports by AN,
    - use power headroom and required power based on QoS class
- **Handoff indication**
  - **AT indicates FL preference by sending R-CQICH to the target with desired FL serving sector (DFLSS) flag set**
  - **AT indicates RL preference by sending R-REQCH to the target**
- **Handoff completion**
  - **Handoff completes when AT receives assignment from the new sector**

Quasi Orthogonal Reverse Link (1)

Rationale

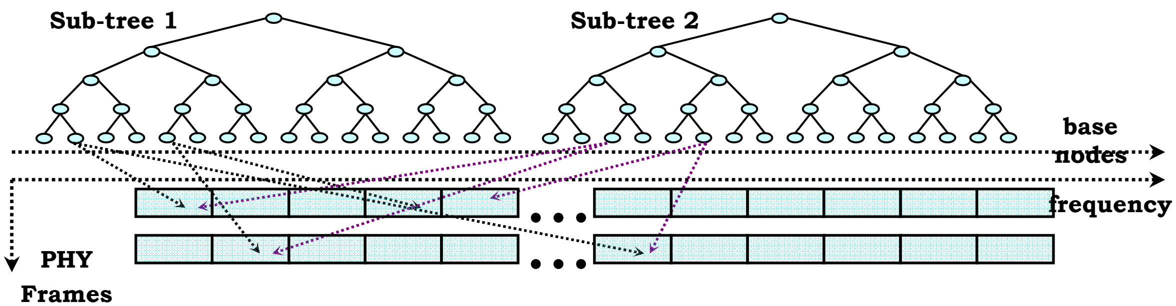
- Non-orthogonal RL (CDMA): capacity scales linearly with the number of receive antennas
- Orthogonal RL: capacity scales logarithmically with the number of receive antennas

Design

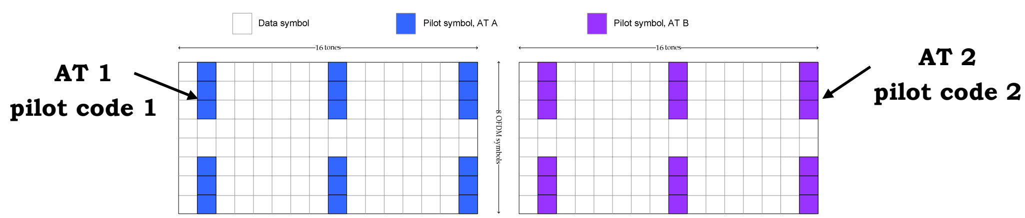
- Superimposing ATs over time-frequency tiles
- Multiple antennas to suppress intra-sector interference space-frequency MMSE receiver
- Intra-sector interference diversity through random hopping
- Orthogonal pilots to improve channel estimation

Quasi Orthogonal Reverse Link (2)

- **Define channel tree with sub-trees**
  - ATs scheduled within one sub-tree are orthogonal
  - different sub-trees map to the same set of time-frequency resources



- **Orthogonal pilots on different sub-trees**
  - orthogonal (DFT) pilot codes over pilot clusters assigned to different sub-trees
  - supports QORL: different pilot codes assigned to different ATs
  - supports softer handoff: different pilot codes assigned to different sectors



Layer Superposed (LS) OFDMA

- **Introduce overloading of OFDMA resources by letting users overlap in time/frequency – separate users by interference cancellation/joint decoding**
- **Key idea is to "layer" users according to achievable spectral efficiency – referred to as Layered Superposed OFDMA (LS-OFDMA)**
- **Overloading is possible per spatial dimension, can even be used without multiple antenna receivers**
- **Orthogonalize users with similar spectral efficiency to be within a layer and achieve intra-layer fairness as in a conventional OFDMA system with scheduling**
- **Let users in different layers interfere with each other and occupy the overlapping bandwidth**
- **Separate layers with interference cancellation or joint decoding**
- **Packet format and bandwidth to all users are explicitly allocated by the AN**

LS-OFDMA Details

- **Layers hop independently of each other**
  - Achieved by scheduling ATs of different layers on different sub-trees
  - Better interference averaging
  - Helps in achieving better fairness – interference cancellation gain from a single user decoding in one layer is spread evenly to many users in the next layer(s)
  - Subband hopping allows for joint hopping of large assignments: enables joint decoding
- **First layer is most aggressive – higher modulation and code-rates and possibly earlier HARQ termination targets**
- **Attempt to first decode all first layer users, cancel those that succeed and then proceed to the next layer**
- **Channel estimation performed for up to first 3 layers of users based on orthogonal pilot resources**
- **Pilot cancellation is performed based on these estimates, and channel estimation is done for the other layers post pilot interference cancellation**
- **Number of non-orthogonal layers will be dynamically determined by AP.**

Fractional Frequency Reuse

- **Fractional Frequency Reuse (FFR) needed in order to improve cell-edge performance without degrading overall capacity (spectral efficiency).**
  - Users at the cell-edge experience low SINRs and low spectral efficiency, so the gain from SINR improvement is significant
  - Beneficial to reduce the other-cell interference for such users.
  - A sector is allowed to schedule cell edge users at the same time and bandwidth that another sector is transmitting to its good user.
  - Low geometry users will be served in different sub-carriers in adjacent cells at the same time (frequency reuse 1/3),
  - At another time, all sub-carriers are used for serving good geometry users in all cells at the same time (universal reuse).
- **Power-bandwidth profiles are created per sector that are defined over sub-zones (collection of nodes) and interlaces.**
  - Such a collection corresponds to a resource set.
- **Lower PSD resource sets create less interference to neighboring sectors whereas high PSD resource sets improve SINR for the target user.**
- **Each resource set in a sector can be allocated a PSD corresponding to the geometry of the users that should be scheduled by that sector over that resource set.**
  - Can make sure that each geometry-class of user, due to interference avoidance gain, is able to experience the desired SINR.
- **The users report a regular wide-band CQI, and a sub-band CQI.**
- **Long-term interference differences, referred to as VCQI, seen over the different resource sets are also signaled at a slower rate (L3 signaling).**
- **Enables the scheduler to have full knowledge of the users' SINRs in order to take the scheduling decisions.**

BCMCS: Broadcast and Supercast

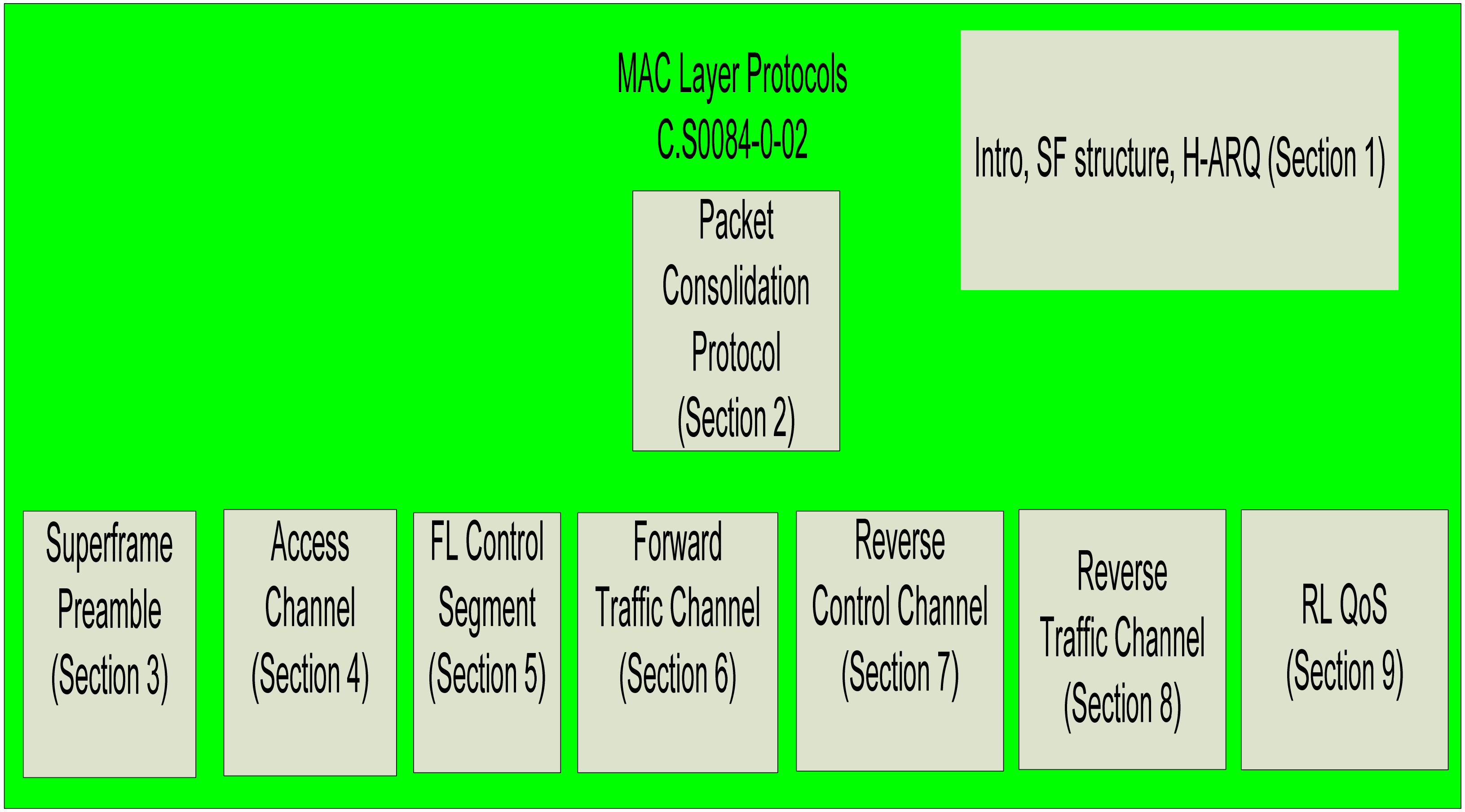
- System supports broadcast services using a single frequency network (SFN) transmission.
- Broadcast sub-bands are defined to be a set of 128 contiguous tones over one interlace.
- At least one sub-band on each interlace is not assigned for BCMCS
  - Needed to carry RL control signaling
- Unicast transmission hopping avoids the sub-bands given to BCMCS.
- Two numerologies for BCMCS, with each deployment uses one format only.
  - Trade-off overhead, operation at high speeds, and delay spreads (up to 40 μs for repeater).
  - BCMCS frames line up with the PHY Frames for regular unicast transmission.
- The coding and modulation used are
  - Inner rate 1/5 turbo code, same as in unicast design
  - Outer Reed-Solomon code to collect time-diversity
  - Support hierarchical modulation for different data rates depending on SNR
  - Two layers of transmission: base layer and enhancement layer
- The packet formats defined support QPSK, 16QAM, 64QAM with modulation step-down.

BCMCS: Broadcast and Supercast

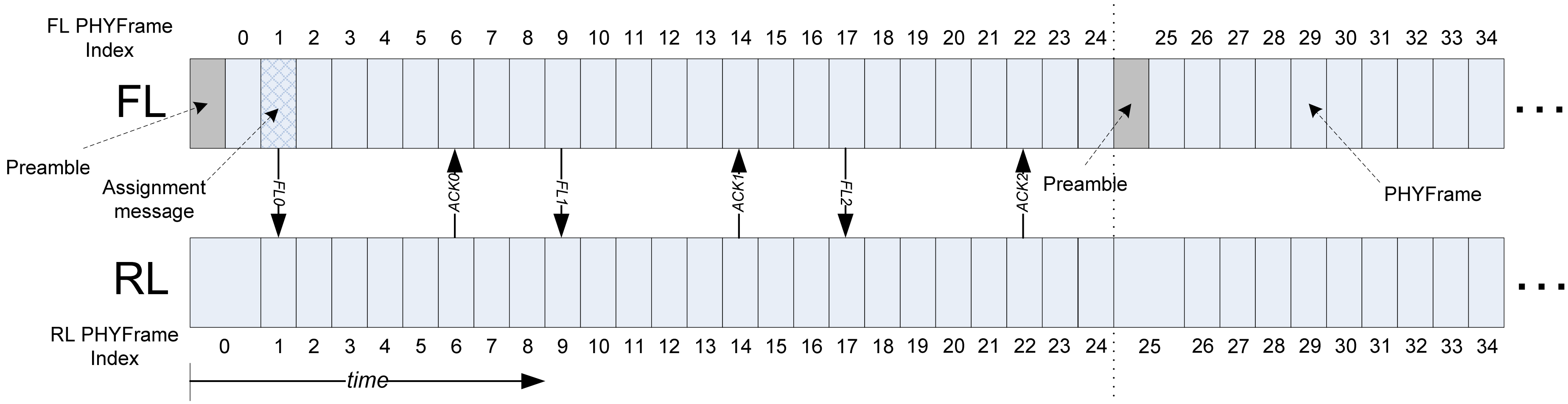
- Variable rate transmission in time domain as well as frequency domain is supported for zone-based BCMCS.
  - This gives a transition from SFN-specific OFDM numerology to unicast OFDM numerology during the transmission of a given packet.
- A logical channel at the enhanced layer can be superposed on a logical channel at the base layer to result in hierarchical modulation
  - Users in better conditions can demodulate hierarchical modulation, and get better quality.
- Support for Supercast, wherein broadcast transmissions are overlapped with unicast transmissions (to good users) in the same time/frequency resources.
- The power-split between broadcast and unicast is sector-specific and interlace, and re-transmission number specific.
  - This gives rise to various degrees of SFN operation.
- The unicast users that are scheduled on top of the broadcast layer decode the BCMCS signal first, and then decode the unicast signal after interference cancellation.

UMBFDD MAC Layer

Structure of the MAC document



8-Interlace Structure without Extended Frames (per C.S0084-0-02)

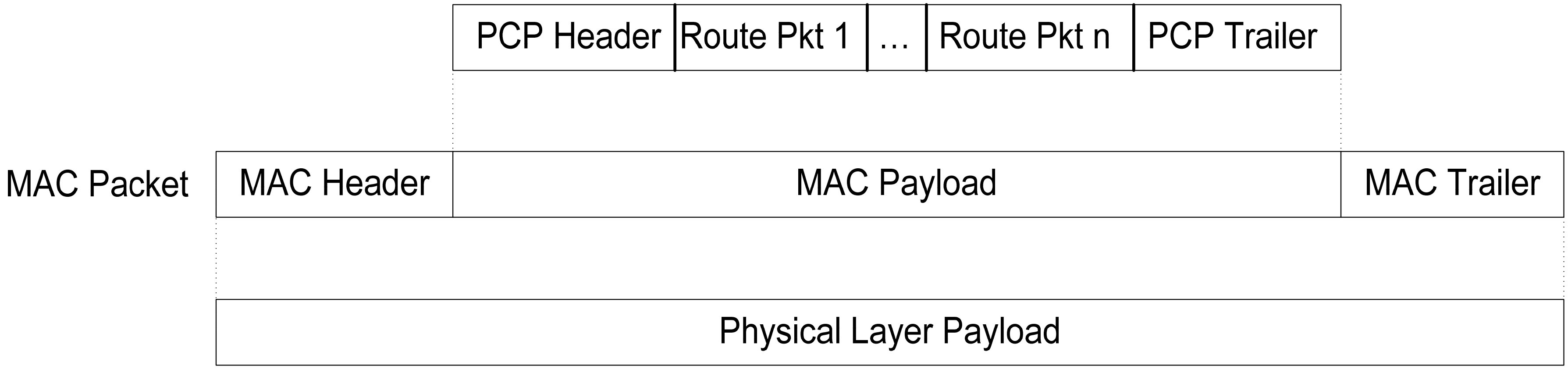


- Each HARQ transmission follows the preceding HARQ transmission after eight PHY Frames.
- FL transmission of a MAC packet on FL PHY Frame k is acknowledged on RL PHY Frame k+5.
- HARQ transmissions for packets that start in PHY Frame k occur in PHY Frames k+8n where n is the transmission index, n=0,1, …
- Support of this interlacing is mandatory

H-ARQ interlaces structures

		FL assignment	Transmission PHY frame	ACK PHY frame	Re-transmission PHY frame	M/O (AT)
FL	8-interlace	N/A	k	k+5	k+8n	M
	8-interlace extended xmit		k, k+1,k+2	k+5	k+8n, k+8n+1, k+8n+2	M
	8-interlace xmit + 2		k, k+1	k+5 / k+6	k+8n, k+8n+1	M
	6-interlace		k	k+3	k+6n	O
	6-interlace extended xmit		k, k+1	k+3 / k+4	k+6n, k+6n+1	O
RL	8-interlace	k	k+3	k+8	k+3+8n	M
	8-interlace extended xmit	k	k+3, k+4, k+5	k+8	k+3+8n, k+4+8n, k+5+8n	M

Packet Consolidation Protocol



- **PCP:**
  - **Receives SDUs (packets from the Route Protocol with disposition information)**
  - **Aggregates them (concatenation based on priority and processing order)**
  - **Encapsulates them between a PCP header and padding trailer**
  - **Transfers the newly formed SDU to the appropriate MAC protocol**
- **Protocol complexity: N/A states/ N/A transitions / 0 commands / 0 indications**

Superframe preamble protocol

Odd SF index	PBCCH	SBCCH	SBCCH	SBCCH	SBCCH	ACQCH	OSICH	OSICH
Even SF index	PBCCH	QPCH	QPCH	QPCH	QPCH	ACQCH	OSICH	OSICH

Channel		Main Payload	How Often
Forward Primary Broadcast Channel	F-PBCCH	SystemInfo block	Every SF
Forward Secondary Broadcast Channel	F-SBCCH	QuickChannelInfo block	Odd SFs
Forward Quick Paging Channel	F-QPCH	QuickPage block	Even SFs
Forward Other-Sector-Interference Channel	F-OSICH	OSI value	Every SF

- 9-bit long **AcqInfo** block sent on the F-OSICH as the 8th OFDM symbol in the SF (TDM3).
- **6 quick page formats** (for various paging loads) using 32-33 bits to identify (possible ambiguously) the paged ATs. The page id compression algorithms are LSB-oriented.
- **Protocol complexity: 2 states/ 2 transitions / 2 commands / 2 indications**

Access Channel protocol

- Used by AT for initial access (AccessType = 0, no MACID) or subsequent access (AccessType = 1, e.g. hard handoff) on a CDMA subsegment of R-ACH
- AT transmits a number of sequences of “access probes”, until either a grant is received (within 5 frames of each transmission) or the AT abandons the effort
- Controlled parameters: initial power level, power level increment from probe to probe, timings between probes and probe sequences (persistence and backoff), number of probes in a sequence, maximum number of sequences, physical layer parameters (e.g. Walsh sequence id, scrambling id, etc.)
- Some parameters set based on access type (e.g. initial or subsequent), AT access class, reason for access (paged or AT-initiated), selectivity of the quick paging format, QoS class of the intended service, etc.

- **Protocol complexity: 2 states/ 2 transitions / 4 commands / 4 indications**

Forward Link Control Segment Protocol

- Covers access grants, resource allocations, H-ARQ, and Physical Layer support (pilots, power control, transmission diversity, timing offset) on 8 channels that together form the FLCS.

- Information content of Assignment Blocks (ABs) messages:
  - **MACID**
  - **Identity of the allocated groups of hop-ports**
  - **Persistence of allocation (e.g. permanent or temporary)**
  - **Packet format**
  - **H-ARQ interlace to use**
  - **Physical Layer support parameters**

Shared Control	Power Control	Pilot Quality Indicator	Fast Other-Sector-Interference	Forward Interference-Over-Thermal	Reverse Activity Bit	Acknowledgement	Start of Packet
F-SCCH	F-PCCH	F-FPQICH	F-FOSICH	F-FIOTCH	F-RABCH	F-ACKCH	F-SPCH
FLAB RLAB PDCAB GRA bitmap	1 PC bit for each AT with an active MACID	PQI bits for all ATs with an active MACID	1 OSI value for each Physical Layer subzone	1 IOT value for each Physical Layer subzone	The RAB value	0 – NOP 1 – ACK, keep 2 - ACK, drop 3 - drop	0 – NOP 1 - start,keep 2 - drop 3 - reserved

- **Protocol complexity: 2 states/ 2 transitions / 2 commands / 2 indications**

Forward Traffic Channel Protocol

- Assignment persistence:
  - Sticky (FL-ATA): until explicitly de-assigned
  - Non-sticky (FL-NS-ATA$_{UC}$/ FL-NS-ATA$_{BC}$): pre-specified duration
  - Residual (FL-R-ATA): opportunistic, when not used by rightful assignee
  - Group (FL-GR-ATA): via GAM + GRA bitmap sent on F-DCH
- Overlapping assignments (general) principles:
  - Assignments of the same types should not overlap
  - Most recent assignment has priority over previous assignments
- Modified assignments
  - Hop-ports can be added/removed from assignments
  - H-ARQ repetitions can be redirected to other hop-ports
- Resource identification via several binary trees:
  - "Leaf" nodes correspond to a group of at least 16 hop-ports
  - Assigned node identifies the node and all its descendants (if any)
- Payloads:
  - MACID_Page: 16, 24 or 32 bit PagingIDs + optional Access persistence value
  - Group messages (Assignment, Assignment Complete, Properties Request), Codebook messages (Assignment, Query, Response)
  - Attribute negotiation via Session Configuration Protocol Messages

- **Protocol complexity: 2 states/ 2 transitions / 2 commands / 5 indications**

Forward Traffic Channel Protocol (cont.)

- **Fundamental unit of assignment is logical subcarrier**
  - **A static resource that maps to a unique physical subcarrier**
  - **Mapping of logical subcarriers to physical subcarriers can change over time (hopping)**
  - **Sets of logical subcarriers are specified using nodes on a channel tree**
  - **Each base node addresses 1 channel unit**
    - Channel unit is 16 tones over 1 PHY Frame (minimum resource allocation unit)

- **Resource-adaptive synchronous H-ARQ on Forward Link and Reverse Link**
  - **Each HARQ transmission follows at a fixed duration after the previous one**
  - **If necessary, the resource assigned to a data packet can be changed "starting at the next HARQ transmission" → "for retransmission" using an assignment message**

- **Assignments can be persistent or non-persistent**
  - **Non-persistent assignments expire after one packet, while persistent assignments persist until supplemented, decremented, de-assigned or packet loss**
  - **Persistent assignments reduce signaling requirements when multiple users are scheduled simultaneously**
  - **Also can be used to eliminate request latency for RL assignments**

- **Grouped Resource allocation (GRA) via bitmap signaling**
  - **Efficient support of VoIP-like applications**

Voice over IP

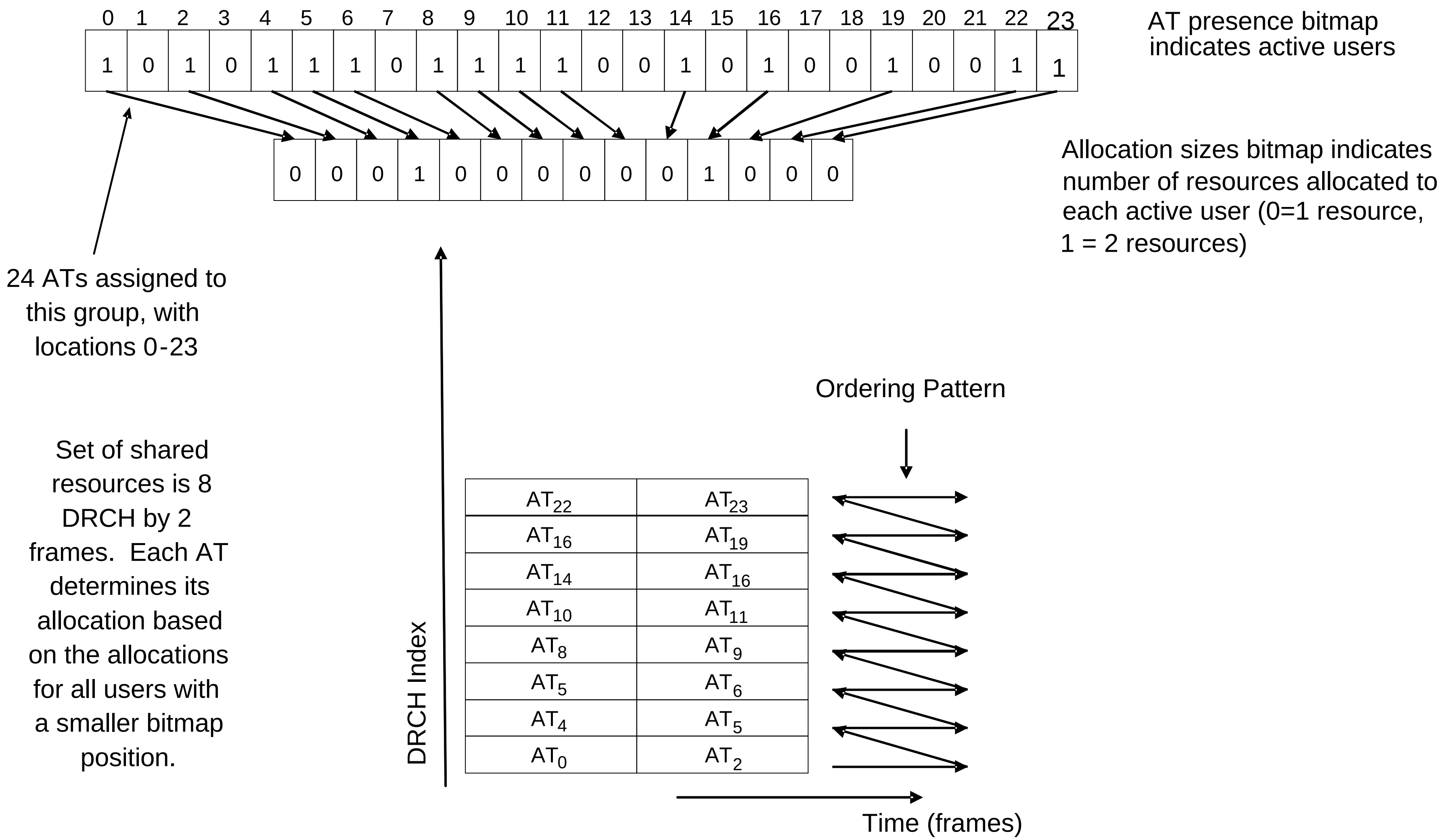
- **Group VoIP users together and assign the group a set of shared time-frequency resources**
  - **Three forms of statistical multiplexing possible**
    - Among group members
    - Between initial and subsequent transmissions
    - Between groups: a common set of time-frequency resources can be shared by two groups
  - **Unused portion of the shared time-frequency resource can be temporarily assigned to other non-VoIP users**
- **Control channel overhead can be divided into two parts**
  - **Layer 3 Call setup messages**
    - Group users and address the group (allocate resources, etc.) with a group ID
    - Overhead minimization less crucial because of infrequency of messages
  - **Resource assignment message**
    - Frame-by-frame messages
    - Overhead minimization crucial
- **Bitmap signaling is used to distribute resources among users with minimum control overhead**

Voice over IP

- **Bitmap consists of up to 3 parts:**
  - A Resource Availability Bitmap is used to indicate which of the set of shared resources are in use
  - An AT Presence Bitmap is used to indicate which ATs are being served in each voice frame, where each AT corresponds to a location in the bitmap
  - An Allocation Sizes or Packet Formats bitmap may be used to indicate number of assigned resources and/or MCS.
- **ATs are assigned resources in each frame using bitmap signaling**
  - Group is assigned a set of shared resources persistently
  - Bitmap signaling is used to determine the exact resource for each AT in each frame
  - Bitmap signaling is used for first and subsequent retransmissions of HARQ
- **2 consecutive PHY frames are concatenated to form a VoIP frame**
  - Transmissions at ~7 ms intervals allow up to ~3 transmissions per vocoder frame (20 ms) without additional delay
- **Residual Resource Assignment**
  - Data ATs can be assigned group resources that would otherwise be unused

Voice over IP

Example Bitmap



Reverse Control Channel Protocol

- Estimation of channel quality:
  - based on most recent F-PQICH value for each sector; best selected as "serving"
- Power control:
  - Initially based on the power of the last successful access probe sent on the Access Channel
  - Subsequently adjusted based on the F-PCCH feedback

Physical Channel		Logical Channel		Content
Pilot	R-PICH			Reverse Pilot
CDMA Dedicated Control	R-CDCCH	Channel quality indicator	r-cqich	4 bits+ 1 bit (Desired FLSS flag)
		Request (RL resources)	r-reqch	6 bits (measure backlog)
		Power amplifier headroom	r-pahch	6 bits (code (Carrier / Thermal) power)
		Power spectral density	r-psdch	4 bits (code Tx/Rx power per sector)
OFDMA Dedicated Control	R-ODCCH	MIMO channel quality indicator	r-mqich	Single Code Word: 7 bits Multiple Code Word: 4 bits per layer
		Channel quality indicator	r-cqich	4 bits
		Request (RL resources)	r-reqch	6 bits (measure backlog)
		Subband feedback	r-sfch	4 bits (subband id) +4 bits (CQI delta)
		Beamforming feedback	r-bfch	6 bits (beam index) + 2 bits (CQI delta)
Acknowledgement	R-ACKCH			'1' – ACK (FL packet with good CRC)

- **Protocol complexity: 2 states/ 2 transitions / 5 commands / 4 indications**

Reverse Traffic Channel Protocol

- **Transmission:**
  - Reverse OFDMA / CDMA Data Channels: R-ODCH / R-CDCH
  - Power computed based on the power of the reverse pilot channel R-PICH
- **Assignment persistence:**
  - Sticky (RL-ATA): until explicitly de-assigned
  - Non-sticky (RL-NS-ATA): pre-specified duration
- **Overlapping assignments (general) principles:**
  - Assignments should not overlap
  - Most recent assignment has priority over previous assignments
- **Modified assignments and resources**
  - Hop-ports can be added/removed from assignments; assignments can be explicitly expired
  - H-ARQ repetitions can be redirected to other hop-ports and increased in number
- **Resource identification via several binary trees:**
  - "Leaf" nodes correspond to a group of at least 16 hop-ports
  - Assigned node identifies the node and all its descendants (if any)
- **"In Band" RL control via 8-bit control blocks:**
  - Power Amplifier Headroom (6 bit)
  - Request (RL resources) (6 bit)
  - C/I changes (5 bit)

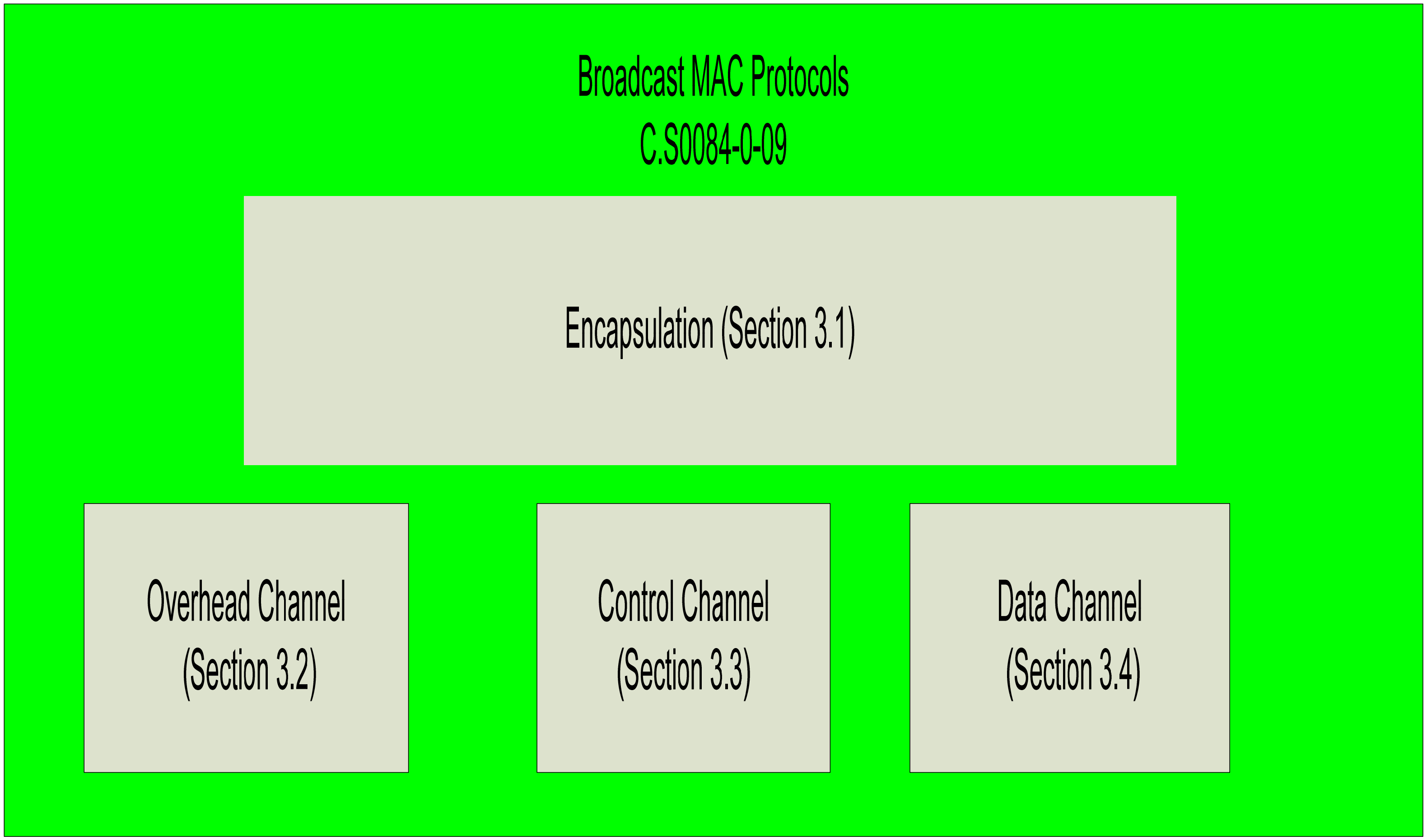
- **Protocol complexity: 2 states/ 2 transitions / 2 commands / 2 indications**

Reverse Link QoS

- **Maintains two token buckets per stream:**
  - “hint”, used for scheduling
  - “max” used primarily for traffic shaping (i.e. dropping packets)
- **Bucket sizes (in octets) grow by (*time x token arrival rate)* and shrink by (*number of transmitted packets x size of packet)***
- **Scheduler is proprietary, but should use:**
  - Priority
  - Age of packet in queue
  - Time limit for the packet’s age
  - Size of the “hint” bucket
  - Size of the “max” bucket
- **Messages and attributes:**
  - Stream Protocol
  - Session Configuration Protocol

- **Protocol complexity: N/A states/ N/A transitions / 0 commands / 0 indications**

Structure of Broadcast MAC sections of the Broadcast Specification



Broadcast MAC Protocols

<table>
<tr><td colspan="12">Data Channel MAC Protocol Capsule (Base)</td><td colspan="12">Data Channel MAC Protocol Capsule (Enhanced)</td></tr>
<tr><td colspan="4">Stream 0</td><td colspan="4">Stream 1</td><td colspan="4">Stream 2</td><td colspan="4">Stream 0 (dummy)</td><td colspan="4">Stream 1</td><td colspan="4">Stream 2</td></tr>
<tr><td>MH</td><td>SH</td><td colspan="2"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td><td>MP</td></tr>
</table>

- **Overhead Channel Protocol**
  - Covers the sending/receiving of the BroadcastChannelInfo message
  - Protocol complexity: 2 states/ 2 transitions / 5 commands / 2 indications
- **Data Channel Protocol**
  - Base and Enhanced MAC protocol capsules with MAC header at the beginning of the capsule
  - 1 MAC Layer Packet is 122 octets
  - 16 packet formats supported (size: 768-3568 octets)
  - Protocol complexity: 2 states/ 2 transitions / 4 commands / 2 indications
- **Control Channel Protocol**
  - Similar to Data Channel encapsulation, but no stream structure
  - Performs Reed-Solomon encoding and generates the erasure control blocks
  - Protocol complexity: 2 states/ 2 transitions / 2 commands / 3 indications

- **Key Exchange Protocol**
  - Pairwise Master Keys are pre-established between AN and AT; up to 3 keys can be active at a time
  - Key in use is determined by matching the encrypted text of a well known clear text string
  - AN and AT generate provisional 128 bit message integrity keys and use them to generate 16-bit digital signatures of the exchanged messages.
  - Those messages are InitialKeyRequest KeyRequest, KeyResponse, KeyComplete, KeyReject, and they carry cryptosync info, transaction identifier info and integrity codes.
  - Upon validating the exchanged messages, AN and AT generate the 256-bit long Temporary Security Key (TSK)
  - Lower half of TSK becomes the message integrity key, upper half of TSK becomes the ciphering key.
- **Ciphering Protocol**
  - Encryption/decryption via AES (Rijndael) uses 128-bit long ciphering key
  - The keys is first “salted”, prior to ciphering
  - Payload can be ciphered as a whole or one octet at a time
  - Cryptosync is based on direction, stream identifier, and associated counters
- **Message Integrity Protocol**
  - 64-bit long authentication tag is generated via AES CMAC function using 128-bit long message integrity key (MIKey)
  - Authentication tag is included into a authentication header and prepended to the message
  - Cryptosync is based on direction, stream identifier, and associated counters

UMBFDD Upper Layers

- **Broadcast Control Protocol**
  - Handles Broadcast Flow Registration requests from AT, which identify the broadcast flows of interest to the AT
  - The 32-bit authorization signature is computed based on the 128-bit long Broadcast Access Key and the current system time
  - The AN may reject the registration for all or specific flows and may order registration at any time
- **Broadcast Packet Consolidation Protocol**
  - Prepends the 16-bit PCP header to the broadcast content packet, broadcast signaling message or tunneled unicast route packets received from the higher layer
  - The header identifies the type of packet, its encryption status, its length and whether it is a first or last fragment of a larger higher level packet
  - After payload ciphering, if performed, the payload packet and PCP header are delivered to the broadcast MAC protocols

Broadcast/Multicast Upper Layers (cont.)

- **Broadcast Security Protocol**
  - AN generates 32-bit long RandomSeed and sends it via the SecurityParameters message
  - RandomSeed and the 128-bit long Broadcast Access Key for the channel are used to generate the 128-bit long Short Term Key (STK)
  - After “salting”, the STK is used to generate the encryption mask for the entire error control block
  - The 64-bit long cryptosync is based on the time stamp for the block
  - Ciphering is performed by octet-wise XOR’ing the payload of the error control block with the encryption mask.
- **Broadcast Inter-Route Tunnel Protocol**
  - Controls the transmission of a unicast packet over the broadcast channel
  - Prepends one or more broadcast inter-route headers, identifying the route and the sector, to the unicast packet
  - The packet and headers are delivered to the broadcast Packet Consolidation Protocol

- **QoS Management Protocol**
  - Tasked with negotiation of packet filters and QoS for IP packets and with mapping of reservations to streams
  - Sends and receives reservation and data requests and responses for the forward and reverse links
  - Employs QoS profiles (currently defined: 60) specified in 3GPP2 C.R1001-F section 13 and QoS parameters (currently defined: 8) specified in 3GPP2 X.S0011-004-D Annex E.
- **Radio Link Protocol**
  - Performs segmentation and reassembly of higher layer packets and Ack/Nak based ARQ using a “sliding-window” algorithm
  - Protocol is parameterized and the parameters are negotiable
  - Tx/Rx functionality in order: add message integrity tag, fragment, cipher, add RLP header , transmit; Rx functionality is reversed
  - Divided into a Segmentation and Reassembly Sub-Protocol and QuickNak Sub-protocol

- **Stream Protocol**
  - 32 streams possible, some with dedicated functionality:
    - **(0) broadcast / manycast**
    - **(1) best effort delivery signaling**
    - **(2) reliable delivery signaling,**
    - **(3) reliable delivery inter-routing tunneling**
    - **(4-6) best effort delivery inter-routing tunneling**
    - **(7-30) available**
    - **(31) reserved for future use.**
  - Prepends/removes the 5-bit header with the stream id to/from the RLP protocol data unit before delivering it down/up the protocol stack.
- **Route Protocol**
  - Prepends/removes the route protocol header(minimum length = 1 bit) to/from the Stream Protocol data unit. The header contains, if necessary, the id of the personality and the id of the AT (e.g. UATI)
  - Decides whether to move the packet along on the local protocol stack for processing or to the Inter-Route protocol for forwarding

- **Signaling Protocol**
  - Defines rules for "well-formed" messages: whole-octet length, transmission order (MSB first), non-ambiguous parsability, extension through addition only
  - Sets up the information required for delivery: forward/reverse/broadcast channel, delivery mode (e.g. Best Effort, Reliable), destination address
  - Adds a 1-2 octet header which identifies the target protocol for the payload
- **Inter-Route Tunneling Protocol**
  - Allows a currently serving node to act as packet relay for a previously serving node, without the need to transfer state information to the currently serving node
  - Moves packets between a local or remote Route protocol and the local RLP
  - Adds/removes one or more (RL manycast) headers which identify the target route, using remote route id, or Pilot PN or the access network identifier of the destination
- ***Referenced* protocols in the Application Layer:**
  - Extensible Authentication Protocol: EAP (IETF RFC 3748)
  - Robust Header Compression: ROHC (IETF RFC 3095)
  - Internet Protocol: IP (IETF RFC 791)
  - Etc.

- **Session Management Protocol**
  - Activated by initial access, awaits for the assignment of UATI and then activates the Session Configuration Protocol
  - "keep alive" functionality and automatically closes dead sessions
  - Complexity at AT: 3 states / 4 transitions / 2 commands / 2 indications
  - Complexity at AN: 3 states / 5 transitions / 2 commands / 2 indications
- **Session Configuration Protocol**
  - Negotiates protocols and attribute values for all the personalities (full configuration) or only for the InUse personality (fast configuration)
  - Negotiating philosophy: initiator (AN or AT) proposes list of values in descending order of preference, the other party selects the most desired acceptable value from the list; if none found, fall-back to default values
  - Full and flexible transaction oriented signaling includes request/response, accept/reject, copy and reset functionality
  - Complexity at AT: 6 states / 9 transitions / 2 commands / 2 indications
  - Complexity at AN: 6 states / 10 transitions / 2 commands / 2 indications

- **Route Control Protocol**
  - Activates/ deactivates protocol stacks (routes) within an AN and AT
  - Performs "keep-alive" functionality on each route
  - Assigns/ de-assigns UATI and Paging id to the AT
  - Supports: a data attachment point route, a session anchor route, as well as the FL Serving route and the RL Serving route
  - Protocol complexity for AT: 3 states / 4 transitions / 4 commands / 5 indications
  - Protocol complexity for AN: 4 states / 7 transitions / 4 commands / 5 indications

- **Air Link Management Protocol**
  - "umbrella" functionality that spawns other connection control protocols
  - Supported registration types: zone-based, distance-based, network-code based, after loss of coverage, power-down
  - TuneAway scheduled intervals allow off-carrier activity
  - Redirection to other carriers, if necessary
  - Complexity at AT: 4 states / 10 transitions / 3 commands / 6 indications
  - Complexity at AN: 3 states / 5 transitions / 3 commands / 6 indications
- **Initialization State Protocol**
  - AT only, covers initial part of the system acquisition
  - Initial selection based on information pre-stored in the AT or obtained during a prior redirect
  - AT searches for pilot, decodes superframe and enough overhead information to allow it to successfully be able to further decode the ExtendedChannelInfo message, which will complete the acquisition
  - Complexity: 4 states / 6 transitions / 2 commands / 1 indications

- **Idle State Protocol**
  - Channel selection (for paging): hash index from list of channels advertised in the SectorParameters message
  - Paging: quick (F-QPCH), full (F-DCH, subsequent superframe), fast repaging
  - Sleeping mode: 3 levels of "decaying" wake-up periods
  - AT has to be up-to-date parameter-wise before performing access
  - Complexity at AT: 4 states / 7 transitions / 4 commands / 3 indications
  - Complexity at AN: 3 states / 5 transitions / 4 commands / 3 indications
- **Connected State Protocol**
  - AT is assigned a MACID and is able to participate in data transfers
  - Support for a SemiConnected state, where the AT cannot use the RL channels, but can receive assignments on the Forward Shared Control Channel.
  - Complexity at AT: 4 states / 6 transitions / 4 commands / 7 indications
  - Complexity at AN: 5 states / 9 transitions / 4 commands / 7 indications

- **Overhead Messages Protocol**
  - Sends the SystemInfo block on F-PBCCH every superframe and the QuickChannelInfo block over F-SBCCH every odd superframe
  - Periodically, sends ExtendedChannelInfo and SectorParameters messages
  - If the broadcast information changes, connected users will be sent the encapsulated version of those messages
  - Complexity: 2 states / 2 transitions / 2 commands / 6 indications
- **Active Set Management Protocol**
  - 3 sets of pilots: Active (in use for traffic and control), Candidate (subject to reporting to the AN when they become strong enough) and Remaining (all other pilots that can be monitored).
  - Promoting/demoting pilots between those sets based on absolute and relative power thresholds
  - Pilot reports generated by AT autonomously or on demand from the AN.
  - The reliably delivered MACResourceAssignment message from AN, synchronizes the Active Set of the AT with the one at the AN.
  - Complexity: 3 states / 5 transitions / 5 commands / 5 indications