

Synchronous DS-CDMA/FDMA PHY Proposal for IEEE 802.16.3

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Purpose:

This presentation summarizes an initial PHY proposal to the IEEE 802.16.3 based on synchronous DS-CDMA.

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Synchronous DS-CDMA/FDMA PHY for IEEE 802.16.3

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Asynchronous vs. Synchronous DS-CDMA

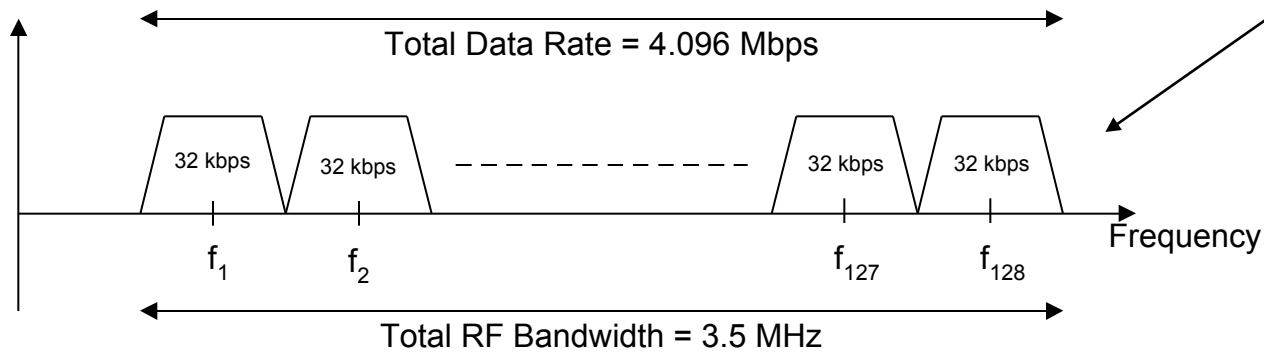
	A-CDMA	S-CDMA
Downstream	Synchronous, orthogonal	Synchronous, orthogonal
Upstream	Asynchronous, non-orthogonal	Quasi-synchronous, orthogonal - orthogonal spreading codes - Chip synchronization within 1/100th of chip time - Practical chip rates < 10 Mcps
Upstream co-channel interference (self-noise)	- Interference increases with active users - Near-far problem (conventional RX) - Less tolerant of out-of-cell Interference	- Low levels of self-noise (up to SIR=30 dB) - Near-far resistant - Tolerates additional out-of-cell interference
Capacity	Interference-limited in upstream	Code-limited in up/downstream
Frequency Reuse	1.5 to 3 typical	1 typical

Multiple Access Scheme

- **S-CDMA**
 - Chip and symbol synchronous
 - RF channel bandwidths from 1.75 to 7 MHz
 - Chip rates from 1 to 6 Mcps (fixed per RF channel bandwidth)
 - Orthogonal, variable-length spreading code sets
 - Spread factors (SF) from 1 to 128 chips/symbol
 - Multi-rate CDMA channels depending on SF
 - Identical I-Q spreading (maximizes spectral efficiency)
 - Randomized spreading code sets for multi-cell deployments
- **S-CDMA/FDMA for large frequency allocations**
 - 1-4 carriers supported w/ S-CDMA on each carrier
 - Variable bandwidth occupancy
- **Channel aggregation for high rate support**
 - S-CDMA/FDMA channel aggregation

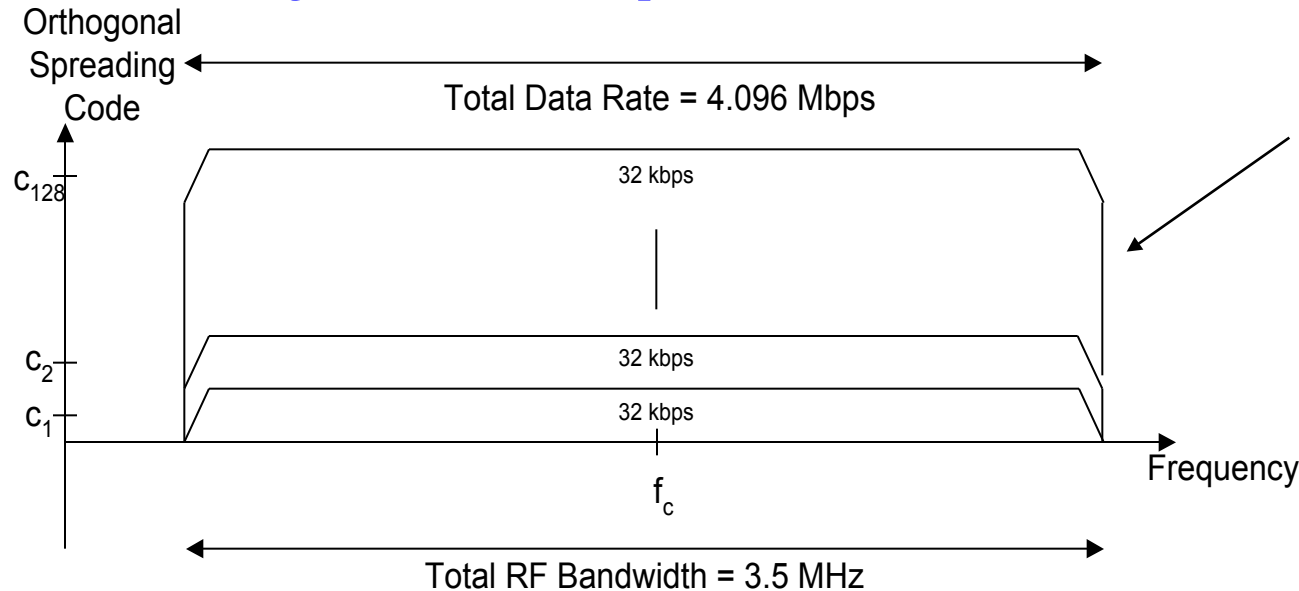
Orthogonal Multiplexing Schemes

Orthogonal Frequency Division Multiplexing (OFDM)



- Carrier aggregation for high rate support.

Orthogonal Direct-Sequence S-CDMA



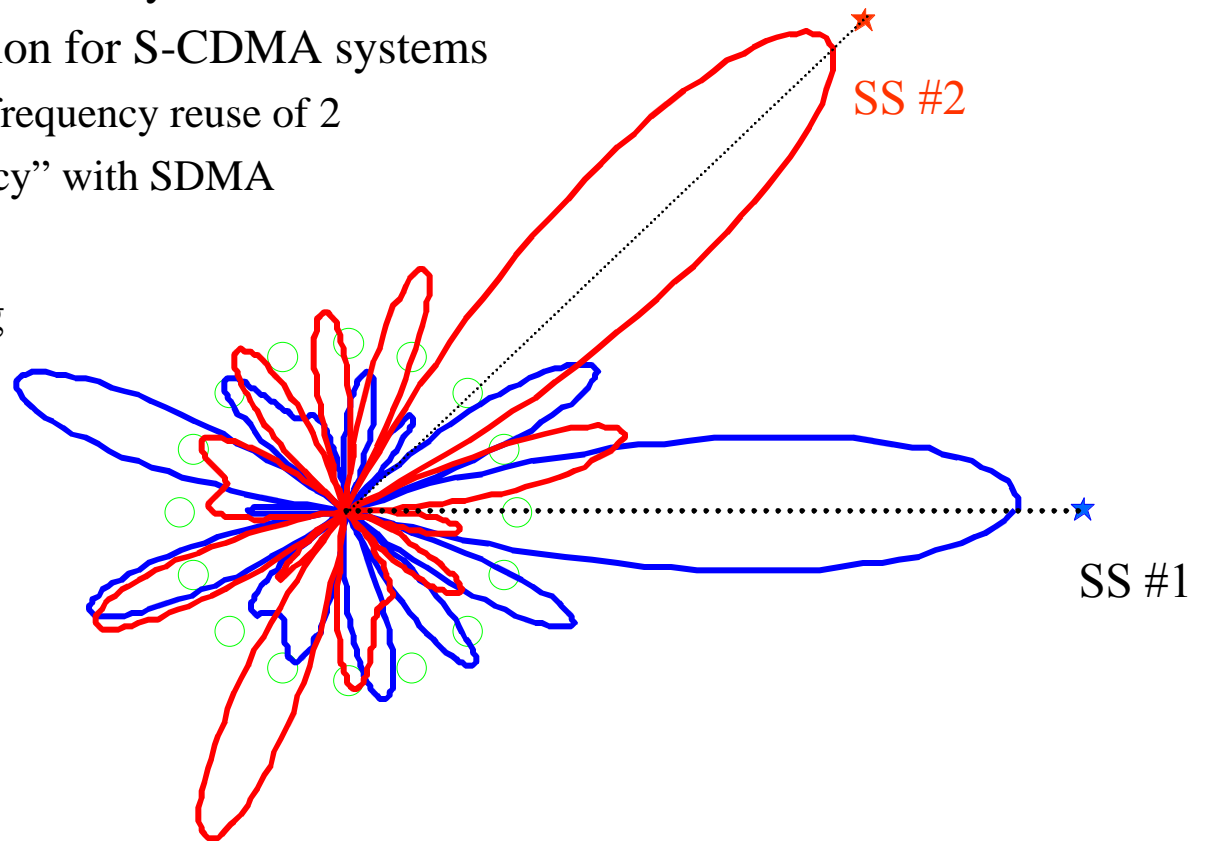
- Spreading Code aggregation for high rate support.
- Multiple, robust lower rate channels.

Duplexing and Data Multiplexing

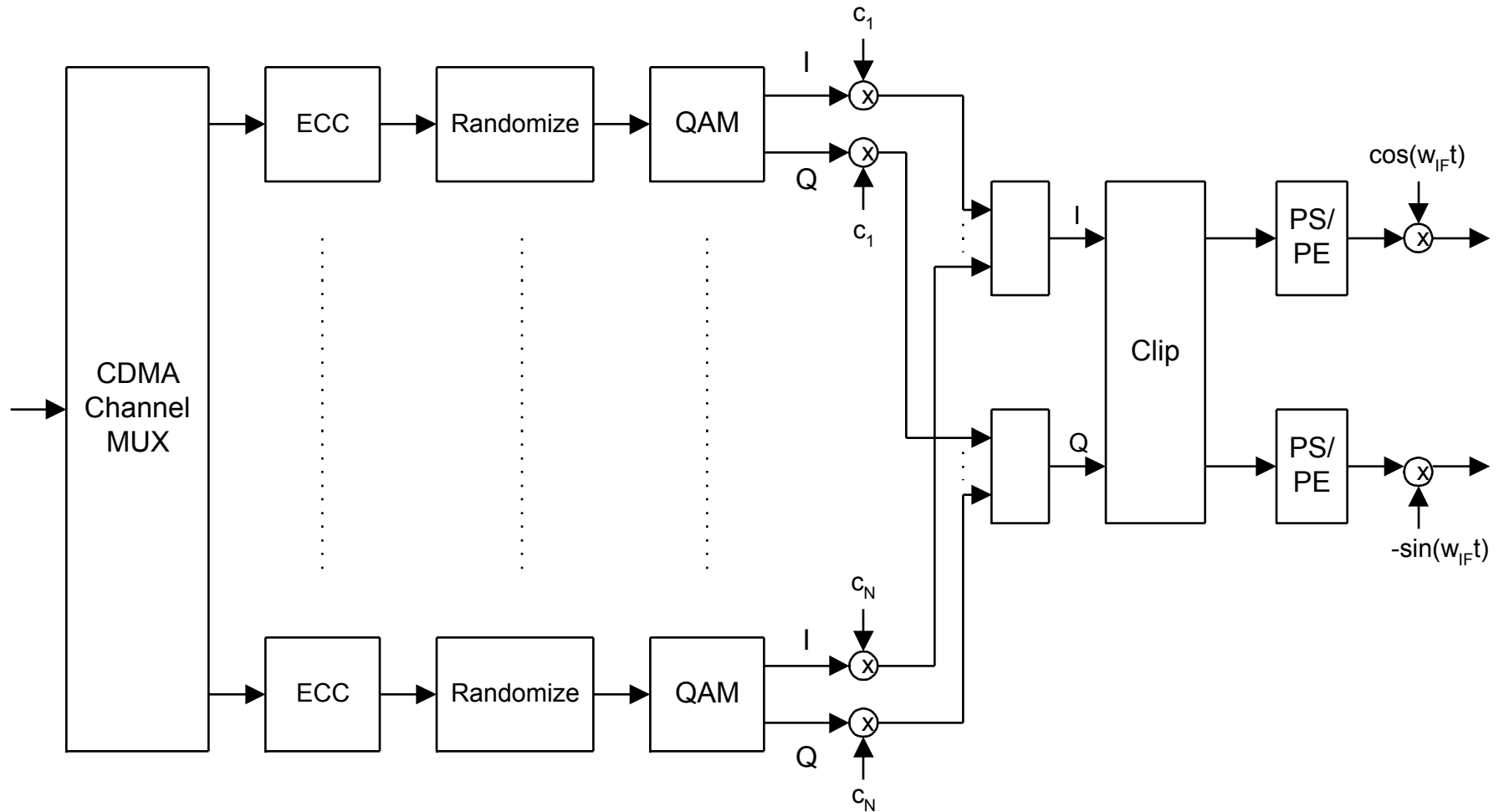
- **FDD or TDD**
- **Flexible Data Multiplexing**
 - Code, Frequency and Time division multiplexing
 - Frequency division of each frequency allocation
 - Code division of each FDMA channel
 - Time division of each CDMA channel with 4-16 ms slot durations
 - Efficient support of reserved and shared bandwidth
 - Dynamic bandwidth allocation/reservation
 - Dedicate aggregated code(s)and/or frequency bands to user(s)
 - Rapid allocation/termination for “fast circuit-switching” and QoS support
 - Application: Lease-line, POTS, VoIP, etc.
 - Shared bandwidth for efficient support of packet-switched services
 - Share aggregated codes and/or frequency bands among users
 - Application: IP traffic and network control/admin
 - Easy bandwidth partitioning between reserved and shared bandwidth
 - Random access
 - Slotted-Aloha upstream random access

S-CDMA w/ Space Division Multiple Access

- SDMA using adaptive beamforming antenna systems
- Spreading code reuse:
 - increases number of channels and cell capacity
 - does not increase peak data rate to/from SS
- Spectral efficiency grows linearly with the number of antenna elements
- Preferred over sectorization for S-CDMA systems
 - Sectorization requires frequency reuse of 2
 - Better “Erlang efficiency” with SDMA
- 16-element beamforming example:



Transmit Reference Model



Waveform Specifics

- **Modulation Formats**
 - Coherent 4 and 16-QAM with optional support of 64-QAM
 - Gray mapping
 - Adaptive modulation based on channel conditions and bandwidth requirements
- **Error Control Coding (ECC)**
 - Punctured, convolutional coding ($K=7$) with rates from $\frac{1}{2}$ to 1 supported
 - High-rate turbo coding [TPC, T-TCM, SCCC, etc.]
 - Adaptive code selection and rate control based on channel conditions, bandwidth requirements and QoS [e.g. BER or delay requirements]
- **Modulation Efficiency**
 - 1 to 6 bits/symbol
 - 1.6 (4-QAM), 3.2 (16-QAM) and 4.8 (64-QAM) bits/symbol typical

Waveform Specifics – cont.

- **Randomization**
 - Independent, symbol-rate data randomization using spreading codes
- **End-to-end Nyquist Pulse Shaping**
- **Multipath Fading Countermeasures**
 - Bore-sighted directional SS antennas
 - Downstream linear equalization at SS (8-16 taps)
 - Upstream pre-equalization at SS
 - Multi-user receiver?
- **Upstream Timing Control**
 - Synchronization to within $1/100^{\text{th}}$ of a chip time
- **Up/downstream Power Control**
 - Mitigates slow fading and reduces interference
 - Enables QoS and reduces power consumption

Capacity and Spectral Efficiency

- **Capacity and Data rates**
 - Data rates from 32 kbps to 32 Mbps to/from a SS
 - Cell capacities from 1 to 150 Mbps
 - CDMA channel aggregation or bonding
 - Flexible bandwidth allocations and rate matching possible
 - With multiple carriers, FDMA channel bonding
 - Capacity is code-limited rather than interference-limited
 - Graceful capacity degradation in extremely harsh environments
- **Spectral Efficiency**
 - Modulation factors from 1 to 5 bps/Hz (up to 50 bps/Hz w/ SDMA)
 - True frequency reuse of one!

3.5 MHz Performance w/o SDMA

Parameter	Coded Modulation		
	4-QAM w/ R=4/5 Coding (1.6 bits/sym)	16-QAM w/ R=4/5 Coding (3.2 bits/sym)	64-QAM w/ R=4/5 Coding (4.8 bits/sym)
RF Channel Bandwidth	3.5 MHz	3.5 MHz	3.5 MHz
Chip Rate	2.56 Mcps	2.56 Mcps	2.56 Mcps
Communication Channel Bandwidth	4.096 Mbps	8.192 Mbps	12.288 Mbps
Peak Data Rate	4.096 Mbps	8.192 Mbps	12.288 Mbps
CDMA Channel Bandwidth (SF=1)	4.096 Mbps	8.192 Mbps	12.288 Mbps
CDMA Channel Bandwidth (SF=16)	256 kbps	512 kbps	768 kbps
CDMA Channel Bandwidth (SF=128)	32 kbps	64 kbps	96 kbps
Modulation Factor	1.17 bps/Hz	2.34 bps/Hz	3.511 bps/Hz

- In 14 MHz using FDMA, capacity and peak data rates from 32 Mbps (16-QAM) to 48 Mbps (64-QAM)

3.5 MHz Performance w/ SDMA

Number of Elements in Antenna Array	4-QAM		16-QAM		64-QAM	
	Aggregate Capacity (Mbps)	Modulation Factor (bps/Hz)	Aggregate Capacity (Mbps)	Modulation Factor (bps/Hz)	Aggregate Capacity (Mbps)	Modulation Factor (bps/Hz)
1	4.096	1.17	8.192	2.34	12.288	3.511
2	8.192	2.34	16.384	4.68	24.576	7.022
4	16.384	4.68	32.768	9.36	49.152	14.044
8	32.768	9.36	65.536	18.72	98.304	28.088
16	65.536	18.72	131.072	37.44	196.608	56.176

Assumptions:

- Chip Rate of 2.56 Mcps
- RF Channel Bandwidth of 3.5 MHz
- Rate 4/5 error control coding
- CDMA code reuse = number of antenna elements

Robustness Advantages

- **Interference**
 - Synchronization reduces self-noise
 - Spread spectrum mitigates interference and narrowband jamming
 - Directional SS antennas reduce adjacent cell interference
 - Beamforming at BS eliminates strong interference sources
- **Channel Impairments**
 - Spread spectrum modulation is robust to frequency-selective fading
 - Directional SS antennas reduce multipath delay spread
 - Linear equalization and pre-equalization combat ISI in multipath channels
 - Adaptive coded modulation, power control and beamforming for flat fading
 - Fade margin for guaranteed availability
- **Radio Impairments**
 - Equalization mitigates linear impairments
 - Adaptive coded modulation mitigates effects of phase noise, group delay and amplifier saturation

Final Thoughts

- **We feel S-CDMA/FDMA combined with SDMA is the correct technology for FWA**
 - CDMA is a field-proven, standardized technology
 - Spectral efficiency and data rates to satisfy FWA
 - Robust with graceful degradation of capacity
 - Cost effective, flexible and scalable
- **We feel a mutually acceptable S-CDMA/FDMA PHY should be standardized in TG3**