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.

Synchronous DS-CDMA/FDMA PHY for IEEE 802.16.3

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Asynchronous vs. Synchronous DS-CDMA

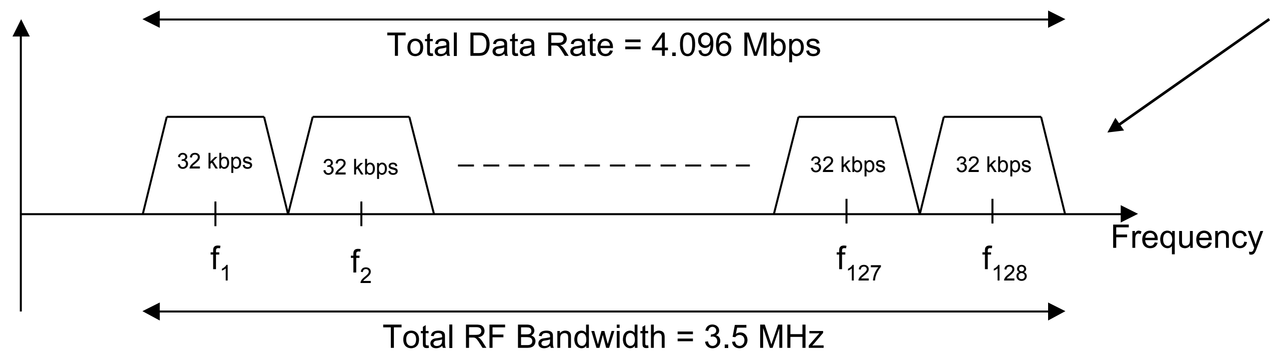
	A-CDMA	S-CDMA
Downstream	Synchronous, orthogonal	Synchronous, orthogonal
Upstream	Asynchronous, non-orthgonal	Quasi-synchronous, orthogonal - orthogonal spreading codes - Chip synchronization within 1/100th of chip time - Practical chip rates < 10 Mcps
Upstream co-channel interference (self-noise)	- 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

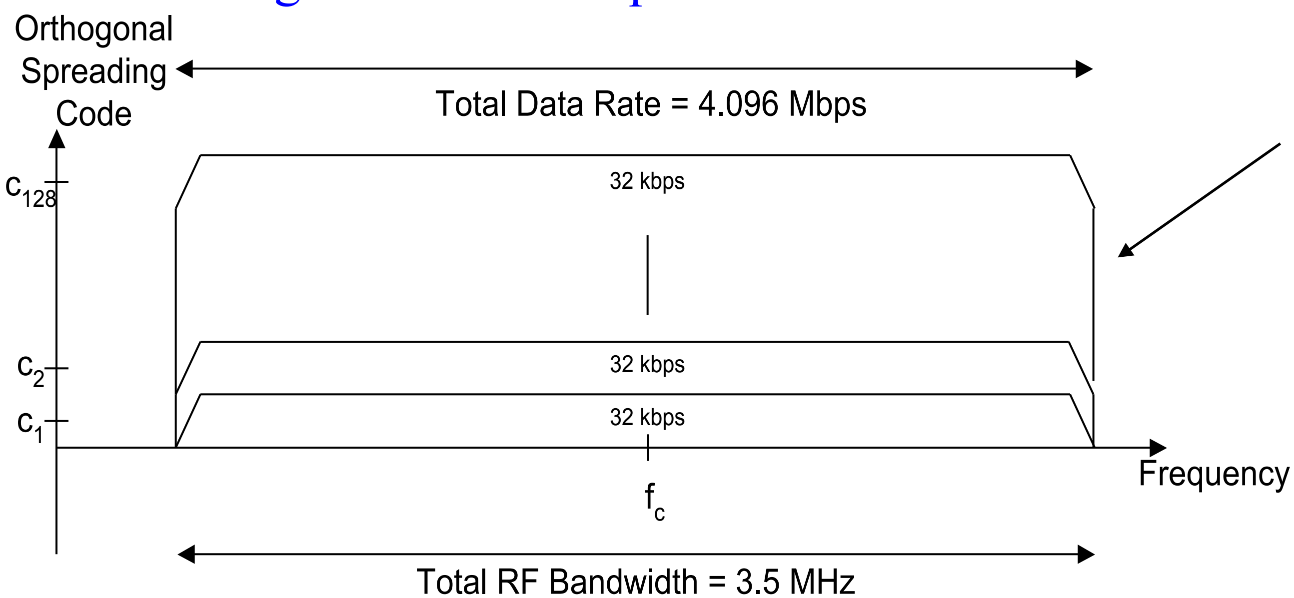
Orthogonal Multiplexing Schemes

Orthogonal Frequency Division Multiplexing (OFDM)



- Carrier aggregation for high rate support.

Orthogonal Direct-Sequence S-CDMA



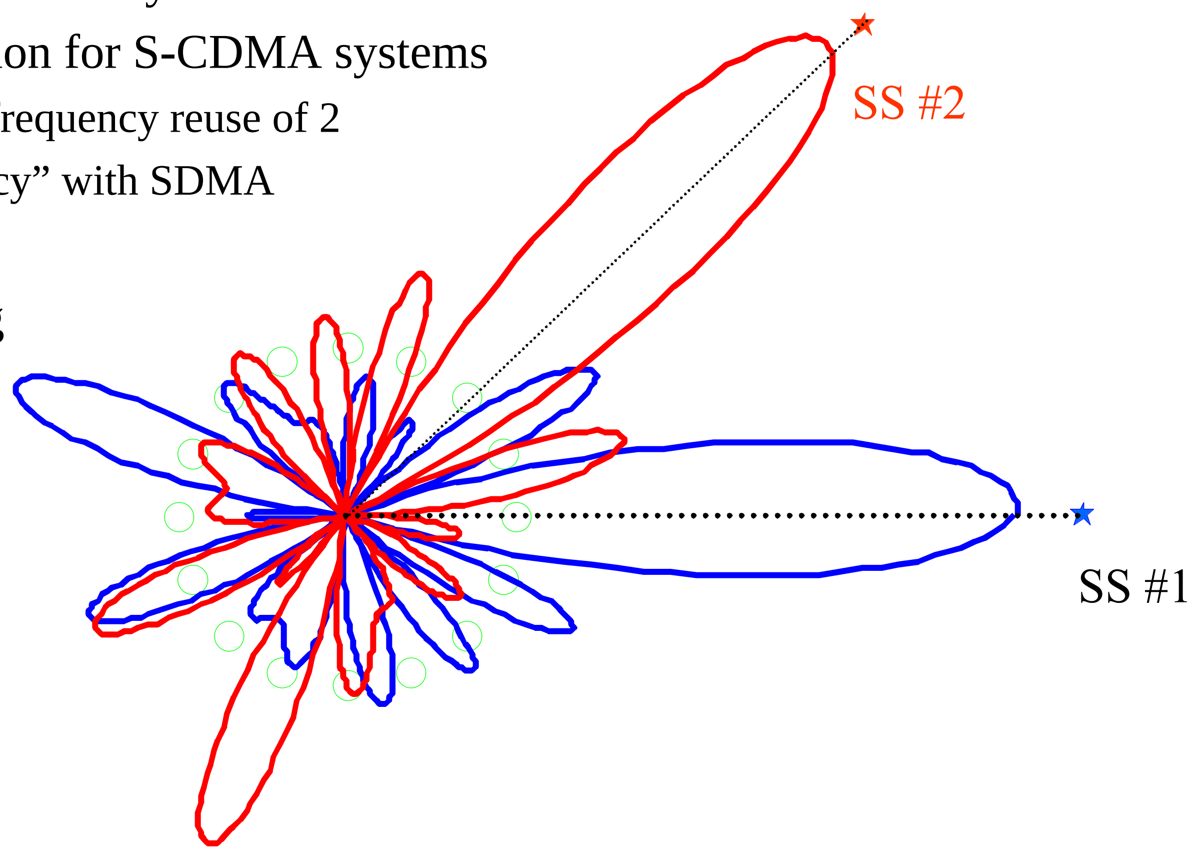
- Spreading Code aggregation for high rate support.
- Multiple, robust lower rate channels.

Duplexing and Data Multiplexing

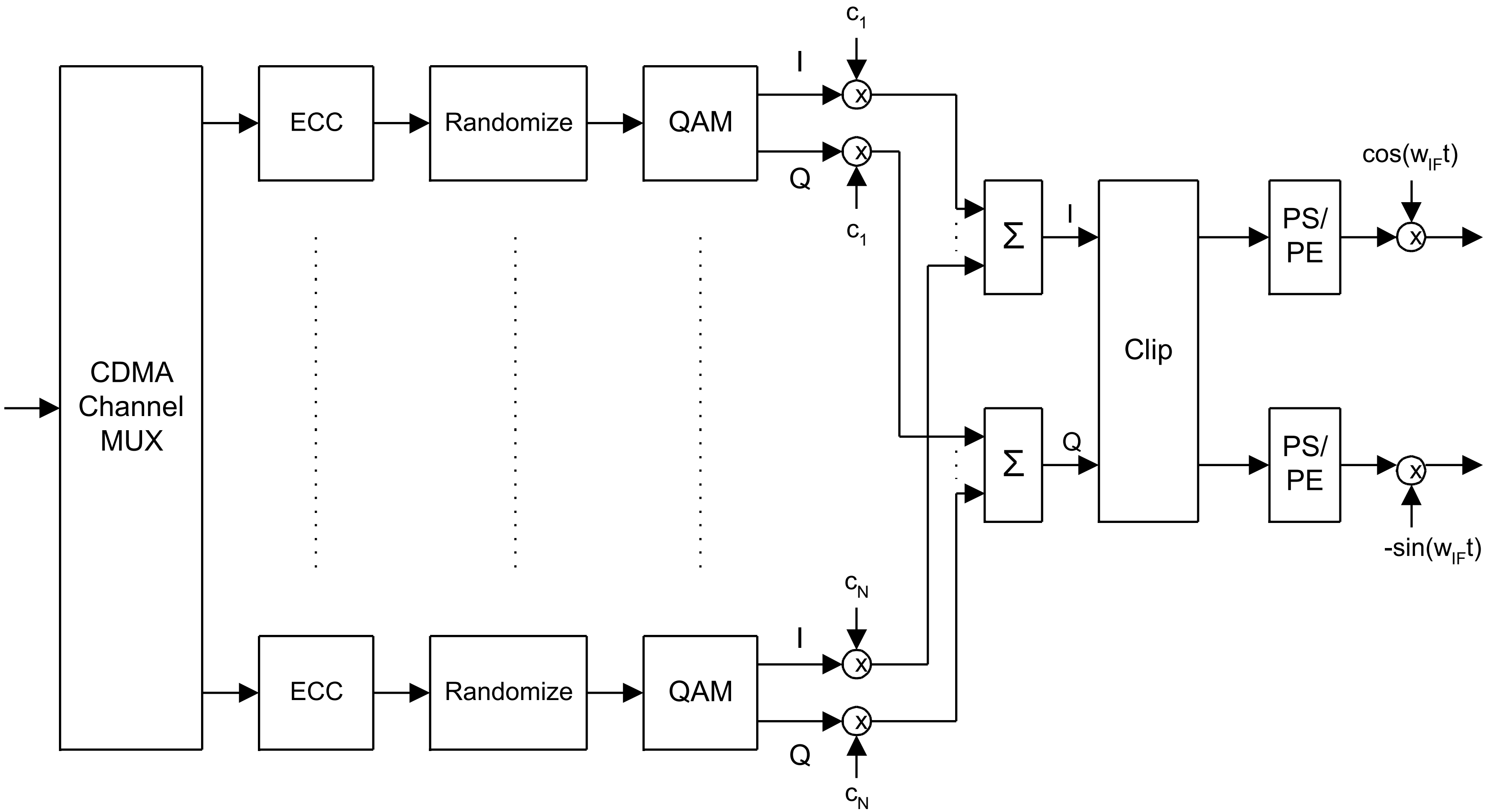
- **FDD or TDD**
- **Flexible Data Multiplexing**
  - Code, Frequency and Time division multiplexing
    - Frequency division of each frequency allocation
    - Code division of each FDMA channel
    - Time division of each CDMA channel with 4-16 ms slot durations
  - Efficient support of reserved and 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 _ 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 1/100th 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

	Coded Modulation		
Parameter	**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**