IEEE C802.16m-08/1004

Project: IEEE 802.16 Broadband Wireless Access Working Group

Title: Supercast with Asynchronous FFR Broadcasting

Date:2008-09-16

Source:
Pantelis Monogioudis and Sridhar Gollamudi
monogiou@alcatel-lucent.com, +1 (973) 386-4804
Alcatel-Lucent, 67 Whippany Road, Whippany, NJ, USA

Venue: Session 57, September 16-19 2008

Abstract:
We present Supercast and three multiplexing schemes for maximizing the sum rate of broadcast and unicast services over an broadcast service area. The schemes differ on the multiplexing approach between broadcast and unicast services. The first basic method uses superposition coding, the second uses FFR for (synchronous) SFN networks and the third uses FFR for asynchronous networks. The later method mainly targets indoor femtocell deployments where symbol level synchronization is difficult to achieve.

Purpose: PHY aspects of enhanced MBS; in response to the TGm Call for Contributions and Comments 802.16m-08/033 for Session 57

Table of contents

Supercast Principle

- During the broadcast slots, each good-coverage sector independently superposes unicast traffic on broadcast traffic. Each sector can steal variable amount of power from broadcast, to serve unicast users with broadcast users seeing slightly higher interference level due to superposed unicast users.
- Existing approaches allow only extremes of full broadcast and full unicast in each sector, either in frequency and/or time, while the proposal presented allows arbitrary power sharing between broadcast and unicast. Supercast can be considered a generalization of the orthogonally multiplexed approach, and is therefore, almost by definition, potentially better in terms of spectral efficiency.

Supercast Principle

- The superposition is based on unicast users being able to decode broadcast (Layer-B) and cancel it out before decoding unicast (Layer-U).
- This is particularly feasible given the SFN nature of the broadcast signal and the significantly higher diversity order of broadcast signals as compared to unicast. Its worth emphasizing that even in the absence of broadcast coverage disparities between cells, each sector could independently superpose unicast traffic to a nearby (high-geometry) user.
- If the unicast user is chosen appropriately, a small drop in broadcast rate could be more than compensated for by achieved unicast rate.
- In addition, *canceling broadcast removes a large part of other-cell interference, so the residual SINR for the unicast layer is likely to be quite high.*

Supercast Design - High Level

- Scheduled unicast transmissions in the E-MBS *FFR sub-band* using E-MBS numerology
  - Superposed transmissions to good geometry users to maximize benefit
  - Scheduled MS is an MS with the capability to do interference cancellation or joint decoding
  - E-MBS power is slightly reduced to accommodate superposed unicast transmissions
- Unicast transmission uses localized (tiled) subcarrier allocation
- Longer CP necessitates a Supercast-specific tile design.
- Superposed unicast capabilities are inherited from existing unicast only subband capabilities, including resource allocation, FFR concepts, MIMO, etc. with the following exceptions.
  - Hopping is restricted within the E-MBS sub-band.

Supercast Design - Signaling

- DL Shared Control Channel (DL-MAP) in the unicast only subbands is used to signal resources for the superposed unicast layer.
  - This means that E-MBS subbands need to be also addressable by the unicast channel tree.
  - No change in definition for unicast only subbands.
  - Signaling to superposed unicast transmissions identical to other (non-superposed) unicast transmissions.
- UL signaling is identical to the non-E-MBS unicast subbands
- Acks are sent only for the superposed unicast layer and hence no change in the UL Ack design needed.
- CQI reports CQI of the E-MBS sub-band.

Supercast Design - Pilot

- New common pilot channel needs to be defined that will also be superposed to the broadcast channel.
- MS will use this channel to calculate a post-IC CQI.
- MS will also used this channel for channel estimation of the unicast channel.

Dynamic Resource Allocation (DRA)

- The management of the power fraction between broadcast and unicast channels must be defined. In its simplest forms, a static power allocation between broadcast and unicast is implemented for each sector.
- Power split in a sector could depend on cell morphology, distance to nearby bases, etc. In its more elaborate form, DRA can be implemented based on reported long-term Broadcast CQI (B-CQI) measured during supercast subframes. Using this information, sectors with better broadcast coverage can dynamically allocate power to superposed unicast resources and/or determine the SFN cluster size.

Synchronous FFR Multiplexing

- A Supercast sub-tree is assigned that is a sub-set of the overall resources.
- FFR multiplexing in Supercast slots between broadcast and unicast, instead of superposition coding.
- Each cell has a portion of the Supercast sub-tree assigned for broadcast; the other portion can be used for scheduling good unicast users with flexible power sharing.
- Each cell transmits broadcast information over a sub-set of the Supercast sub-tree nodes.
- Mapping of modulation symbols is such that over any overlapping portion of the band, the broadcast signal sees an SFN SINR.
- Design to try to overlap unicast portion of Supercast sub-tree with unicast portions in other cells so as to improve the SINR for unicast users.
- Combined channel estimation performed only over tiles that have the same SFN order to ensure correct estimation of SFN channel.

Symbol-level, packet-level synchronization

- Symbol-level synchronization
  - Tightly synchronized OFDM transmissions from all cells combine over the air (SFN)
  - In an ideal SFN desired signal power is the sum of received powers from all cells and interference is zero: SINR is greatly enhanced
  - SFN assumes very tight synchronization requirements between cells
  - Suitable for macrocellular outdoor installations
- Packet-level synchronization
  - The same packet must be transmitted at the same time from all cells
  - Places tight constraints on base station backhaul delays
  - Time-stamping and buffering of backhaul traffic is usually required
  - Difficult if the backhaul is an IP network with poor delay guarantees
  - *Is it really feasible to implement SFN on a on flat IP network ?*
- Asynchronous deployments are envisioned for 802.16m.
  - Indoor installations (e.g. shopping mall)
  - Installations consist of inexpensive pico/fempto-cells.
  - Difficult or expensive to achieve GPS synchronization indoors.

The Broadcast Transmission Problem

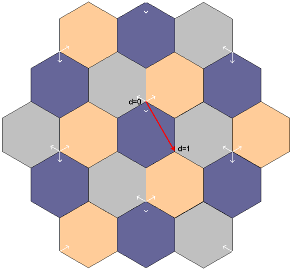
- Consider one transmitter and K receivers with unicast capacities $C_1, C_2, \cdots, C_K$. The multicast capacity of the system—defined as the maximum transmission rate of the multicast signal that can be decoded by all K users with arbitrary reliability—is $\min\{C_1, C_2, \cdots, C_K\}$
  - Capacity of a multicast system is limited by the worst-case user
  - Transmission rate can be increased by allowing some coverage holes, but is still determined by the lower tail of unicast user capacity distribution
  - Improving achievable rates for high SINR users does not enhance achievable multicast rate
- Given multiple transmitters in a cellular network, each with a given amount of power and bandwidth,
  - what is the capacity of multi-cell broadcast transmission?
  - what is a transmission scheme that achieves this capacity?
- Single Frequency Network (SFN) operation is a good strategy in general, but is it optimal in all deployment environments ?

The Alternative

Asynchronous FFR transmission with LLR combining

- Fractional Frequency Reuse combined with macrodiversity at the LLR level
- Multiple cells transmit the same packet at possibly different times using OFDM modulation
- Different cells use different sets of OFDM sub-carriers to reduce interference
- Different cells use different rate matching patterns
- Receiver demodulates symbols received from all monitored cells and combines LLRs in the IR buffer
- IR gain is obtained
- Synchronization not required at the symbol or packet level

Example Frequency Plan Using Static FFR of 1/3

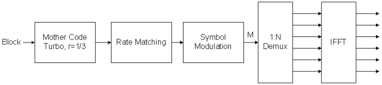


- Mobile locations lie on the red line
- d is the normalized distance: $d = 0$ at the cell site and $d = 1$ at cell corner
- Figure shows only two tiers of cells; calculations are based on 3 tiers of cells.

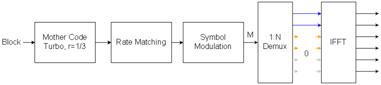
Asynchronous FFR Broadcasting (1/2)

- The same packet is transmitted from all cells at possibly different times
- Coded packet is punctured and mapped to only a third of the total number of tones in each cell; diverse puncturing patterns provide IR gain
- Receiver demodulates symbols separately from each monitored cell and combines LLRs

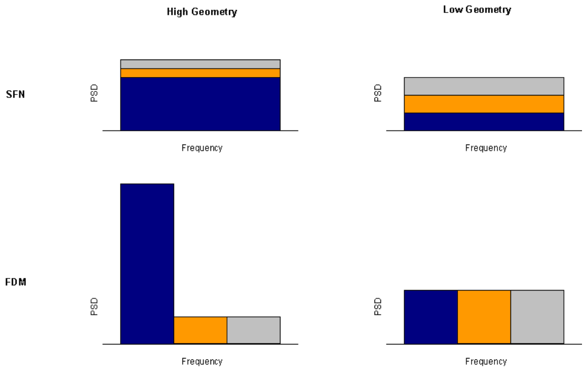
SFN transmitter in any cell:



AFB transmitter in a blue cell:



Asynchronous FFR Broadcasting (AFB) (2/2)

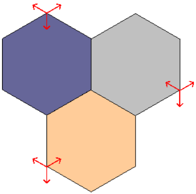


- Consider a simplified scenario with only three cells – one blue, one orange and one gray
- The same total signal energy is received with SFN or Asynchronous FFR Broadcasting
- AFB reduces effective signal bandwidth for a high geometry user; but such users are not critical for broadcast performance
- Performance is the same if a mobile sees equal powers from the three cells
- Caveat: If symbol synchronization is absent, there may be some leakage of adjacent cell power into the sub-carriers used by a cell

Preliminary Numerical Analysis (1/3)

The following is an approximate calculation of AFB performance relative to SFN at different cell locations.

- Assumptions:
  - A three-cell cluster is considered
  - The number of paths in each cell is large
  - Because of the high multipath diversity and macrodiversity, it is assumed that the resulting PSD is ergodic in frequency, i.e., that it samples the entire Rayleigh distribution in one block



Preliminary Numerical Analysis (2/3)

Since the channel is assumed to be ergodic in frequency in one block, we can write the capacity of any block for a user as

$$C(\gamma) = E\{\log(1 + \gamma|h|^2)\},$$

where h is a circularly symmetric complex gaussian with $E\{|h|^2\} = 1$, and γ is the combined symbol SINR.
The above expression can be reduced to

$$C(\gamma) = e^{1/\gamma} E_1\left(\frac{1}{\gamma}\right),$$

where

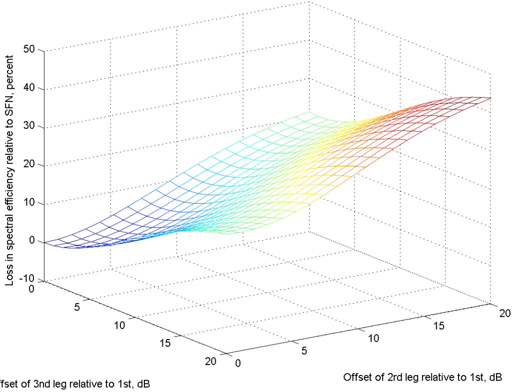
$$E_1(x) = \int_x^\infty \frac{e^{-t}}{t} dt$$

is the exponential integral.

Preliminary Numerical Analysis (3/3)

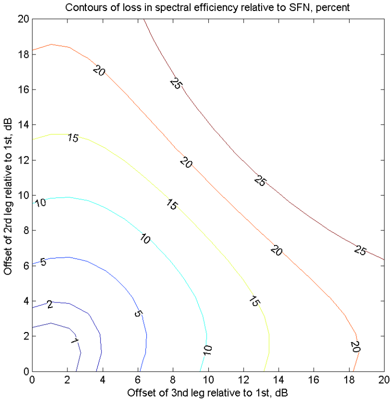
- Let $\gamma_1, \gamma_2, \gamma_3$ be the average symbol SNRs from the three cells to any mobile, assuming each cell used all the symbols (OFDM tones).
- In an SFN, all M symbols experience SINR of $\gamma_1 + \gamma_2 + \gamma_3$. So the spectral efficiency is $C(\gamma_1 + \gamma_2 + \gamma_3)$ bits per symbol.
- With AFB, M/3 symbols see an SINR of $3\gamma_1$, another M/3 symbols see $3\gamma_2$ and the other M/3 symbols $3\gamma_3$. So the average spectral efficiency is $(C(3\gamma_1) + C(3\gamma_2) + C(3\gamma_3))/3$ bits per symbol.
- When all three cells are equally strong, i.e., $\gamma_1 = \gamma_2 = \gamma_3$, then the capacities are the same with AFB and SFN.

Numerical Results: Spectral Efficiencies with SFN and AFB



- Primary leg symbol SNR (without interference) assumed to be 10 dB

Percent Loss in Spectral Efficiency Compared to SFN



- SFN and AFB have comparable performance when the three leg powers are close to each other (likely event for low geometry users)

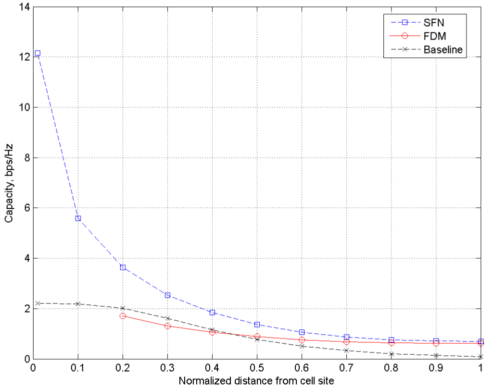
Capacity Comparison at Different Mobile Locations (1/4)

- Calculation of user capacities at different locations in the cell
- Three transmission schemes are considered:
  - Baseline: Independent transmissions in each cell
  - AFB using a 1/3 reuse pattern
  - SFN combining across 56 sectors (3 tiers)

Simulation Parameter	Value/Assumption
Cell layout	56-sector, cloverleaf, 3 sectors/base-station
Signal bandwidth	5 MHz
Sub-carrier spacing	15 kHz
Cyclic prefix length (non-SFN)	4.76 μs
Cyclic prefix length (SFN)	16.67 μs
Cell transmit power	20 watt
Penetration loss	20 dB
Noise figure	10 dB
Shadowing	No

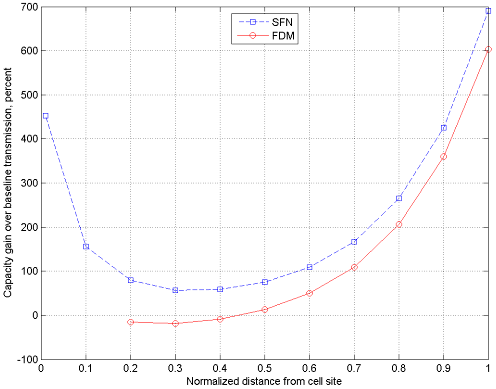
Capacity Comparison at Different Mobile Locations (2/4)

Capacity at different locations with baseline, AFB and SFN:



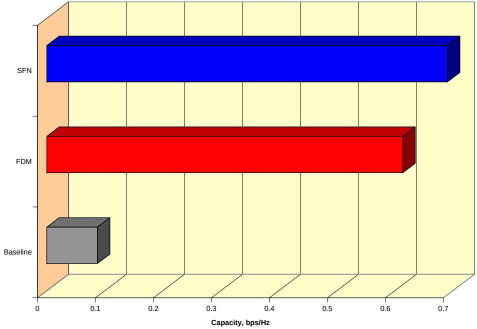
Capacity Comparison at Different Mobile Locations (3/4)

Capacity gains of SFN and AFB over the baseline:



Capacity Comparison at Different Mobile Locations (4/4)

Broadcast cell capacities (equal to worst-case user capacities):



Asynchronous FFR Broadcasting vs. SFN

Advantages of AFB:

- Performance of AFB expected not to be far behind SFN
- No need to synchronize symbol timing between cells for performance
  - Symbol synchronization reduces receiver complexity by not requiring multiple FFTs
- No need to synchronize packet scheduling instants
  - Eases requirements on the backhaul and inter-scheduler communication
- Unlike SFN, a long cyclic prefix is not required for AFB, resulting in a smaller overhead for AFB

Disadvantages of AFB:

- Higher receiver complexity as the mobile will need to demodulate signals and pilots from different cells
- Packet sequence numbers will need to be signaled over the air to enable the mobile to combine the packet received from different cells.

Conclusions

- Supercast allows the tradeoff between broadcast quality and sum capacity across the SFN cluster.
- In SFN deployments, either superposition or FFR multiplexing is feasible. The later can approximate the gains of superposition for inexpensive terminals whose capability does not allow SIC receiver implementation.
- In deployments where symbol synchronization is difficult, asynchronous FFR broadcasting promises to provide performance close to SFN.