Proposal for IEEE 802.16m Resource Allocation and Control Structure

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Re: IEEE 802.16m-08/005 – Call for Contributions on Project 802.16m System Description Document (SDD), on the topic of "Downlink Control Structure"

Purpose: Adopt the proposal into the IEEE 802.16m System Description Document

Scope

- This contribution presents the IEEE 802.16m resource allocation and control structure for single carrier operation.
- This is part of the overall control structure framework as described in contribution C802.16m-08/173.
- The resource allocation and control structure for multi-carrier operation is presented in a separate contribution (C802.16m-08/178).

Background (1/3)

- The legacy 16e system uses a two dimensional approach to assign resources to users. This requires a lot of overhead in signaling the assigned resources.
- Other systems such as LTE and UMB use a one dimensional approach based on a channel tree to reduce the resource assignment signaling overhead.
  - Each assigned user is allocated resources by assigning a node from the tree.
  - Although a channel tree can save in signaling overhead, there are some restrictions in the number of base nodes that can be assigned.
  - For example, if a binary tree is used then only 2, 4, 8, 16, etc nodes can be assigned. Also, if more granularity is added to the tree the total number of nodes increases, which increases the number of bits that are required to signal each assignment.
- The legacy 16e system is also inefficient in power since it relies on broadcasting and/or multicasting assignment information.
  - Both UMB and LTE systems have lower power overhead since the assignment information is transmitted using separate unicast messages, which are power controlled to the each user individually.
- The legacy 16e system uses a TDM approach for multiplexing control and data within a sub-frame.
  - Since the assignment information is located in the same region of the sub-frame in all sectors and since the information is a multicast message, no power boosting can be applied.

Background (2/3)

Resource Allocation	**Pros**	**Cons**
One dimensional, with a channelization tree	• Lower overhead than two dimensional	• Reduced flexibility as well as resource granularity • The overhead increases with higher granularity
Two dimensional	• More flexibility	• High overhead

Multicast/Unicast Control	**Pros**	**Cons**
Multicast	• Common information can be signaled once • Better suited when a group of MS shares the same attributes	• Power must be targeted to the lowest geometry user that is assigned
Unicast	• Power efficient	• Common information must be signaled to each user individually

Background (3/3)

TDM versus FDM of Control and Data	**Pros**	**Cons**
TDM	• Allows for micro-sleep	• Less effective power boosting due to lower pooling efficiency • Control channel granularity is one symbol
FDM	• Power can be boosted • Increased control channel granularity • Simplifies power management	• Does not allow for micro-sleep

IEEE 802.16m System Requirements

- The TGm SRD (IEEE 802.16m-07/002r4) specifies the following requirements:
  - Section 6.10 System Overhead
    - "Overhead, including overhead for control signaling as well as overhead related to bearer data transfer, for all applications shall be reduced as far as feasible without compromising overall performance and ensuring proper support of systems features"
  - Section 7.1 User Throughput
    - The target average user throughput and cell edge throughput is 2 times that of the reference system.
  - Section 7.2.1 Sector Throughput and VoIP Capacity
    - The target sector throughput is 2 times that of the reference system.
- The proposed resource allocation and control design targets the above requirements.

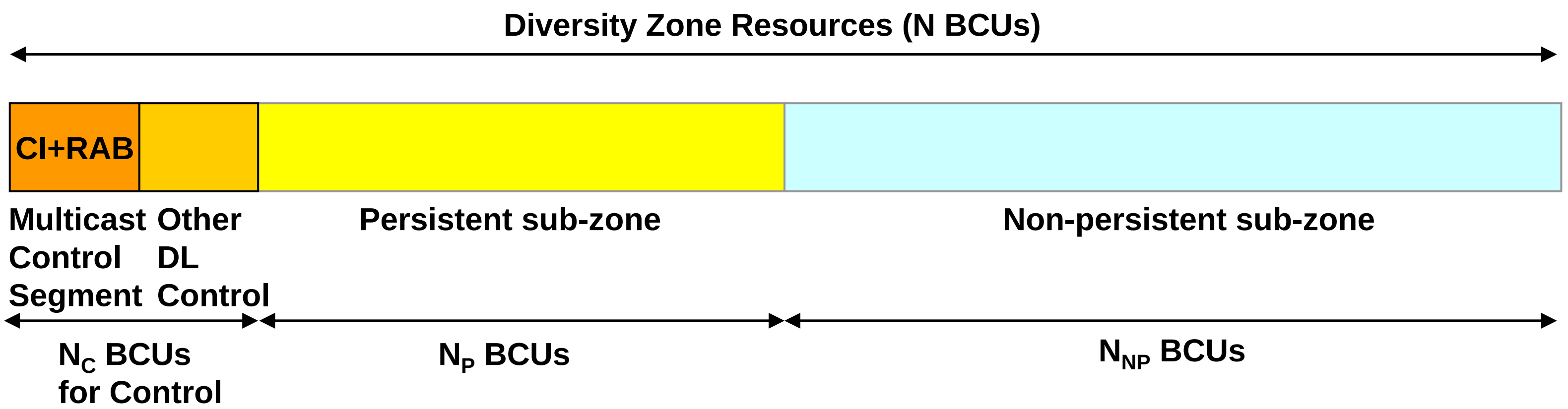
Motivation

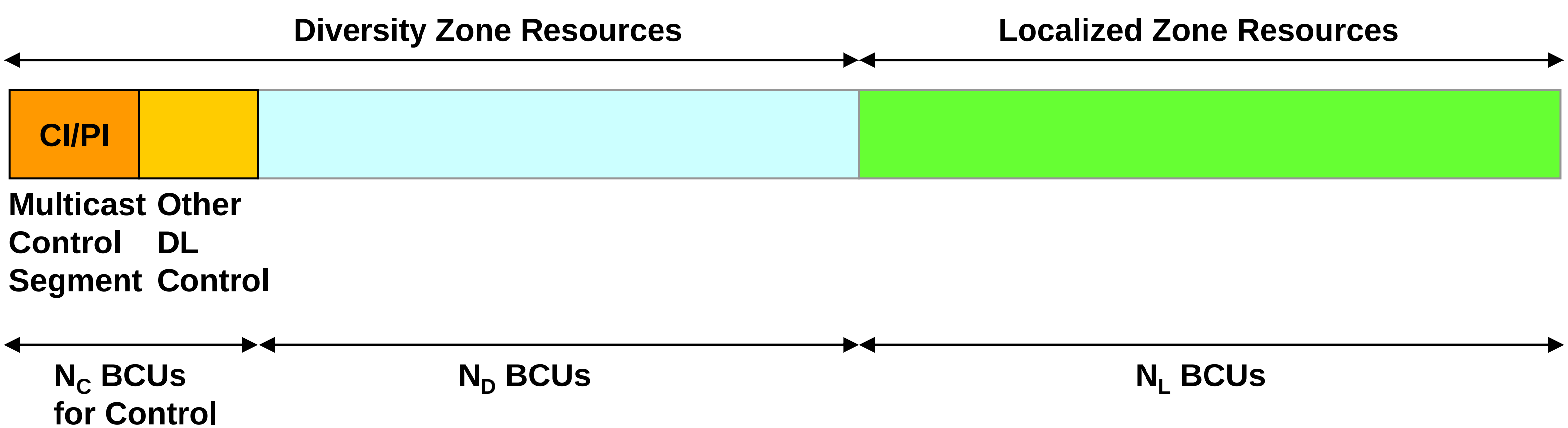
- In order to improve the overhead of the control channel of the legacy system and make it better than existing systems such as UMB, LTE, a new control channel design is proposed for IEEE 802.16m sub-frames.
- The control and traffic channels are confined within each sub-frame and span across all the symbols within the sub-frame.
- Extended sub-frames can be defined to concatenate the sub-channel resource across multiple sub-frames to reduce control overhead and improve UL coverage. This is for FFS.
- The control channel consists of a short multicast message and separate unicast messages for each assignment.
  - Multicast message is kept very small since it is power controlled to the lowest geometry user that is assigned in the given sub-frame.
  - Each unicast message is power controlled to the intended user.
  - Group assignments messages are used for VoIP. The contents of the group assignment message is described in another contribution (C802.16m-08/177).
- The multicast message is a 10 bit message that is used to indicate how the available resources are partitioned. The partitions are not associated with any channelization tree so there is no restriction to the number of resources that can be assigned to a mobile.
- The multicast message also removes the need of signaling a node ID for each assignment. This leads to a significant reduction in overhead since most channelization trees use 9-11 bits for signaling a node ID. The reduction in overhead increases as the number of assignments increases.

Overview of Resource Allocation and Control Structure (1/2)

- The bandwidth can be divided into one or more zones, which can be either diversity zones or localized zones. Each zone consists of an integer number of Basic Channel Units (BCUs) (see contribution C802.16m-08/175).
- Separate control channels are defined within each zone to assign resources within the zone.
- The multicast control segment plus other DL control channels (e.g. HARQ ACKs, power control bits) consist of an integer multiple of BCUs
- A diversity zone can contain a persistent sub-zone and a non-persistent sub-zone. A localized zone contains only the non-persistent sub-zone.
- The multicast control segment indicates how the available resources are partitioned.
  - This includes unused resources in the persistent sub-zone as well as the non-persistent sub-zone.
  - The multicast control segment for a diversity zone consists of a combination index (CI) and if persistent resources are allocated it consists of a resource availability bitmap (RAB) (see VoIP contribution C802.16m-08/177).
  - For a localized zone, the multicast control segment consists of a permutation index (PI).
- The multicast control segment is power controlled to the lowest geometry user that is assigned within the sub-frame.
- The multicast control segment sent in a diversity zone along with other multicast and broadcast channels.

Overview of Resource Allocation and Control Structure (2/2)





Content of Multicast Control Segment for a Diversity Zone

- The multicast control segment consists of a 10 bit combination index.
- The index is an index into a look-up table that consists of all possible combinations of an ordered list of k partitions of size $n_1, n_2, \ldots, n_k$, where $\Sigma n_i = N$, $i = 1, 2, \ldots, k$. The partitions in each list are ordered in increasing size.
- In order to reduce the size of the combination index, a fixed maximum number of assignments is assumed. The maximum number of assignments depends on the number of available resources. If more assignments are needed then a second combination index is used to further partition the resources.

Combination Index	**Number of Partitions**	**Partitioning of 10 Available Resources**
0	1	10
1	2	1,9
2	2	2,8
3	2	3,7
…	…	…
	3	1,1,8
	3	1,2,7
	…	…
	10	1,1,1,1,1,1,1,1,1,1

Combination Index Look-up Table

- The combination index look-up table depends on the number of resources available.
- The table below shows the number of users that can be assigned with one combination index (10 bits) for a given number of available resources.
- For bandwidths that contain more than 24 BCU, multiple combination indices are used.

Number of Available Resources (N)	**Maximum Number of Assignments Using a 10 Bit CI**	**Comment**
< 23	N	All combinations can be signaled with one CI
23	10	Two CIs are needed if there are more than 10 assignments
24	8	Two CIs are needed if there are more than 8 assignments

Example Using the Combination Index

- For example, if there are a total of 24 BCUs and 4 mobiles are scheduled as follows
  - MS 1: 6 units
  - MS 2: 4 units
  - MS 3: 10 units
  - MS 4: 4 units
  - The combination index corresponding to CI(4,4,6,10) is signalled on the multicast control channel.
- The maximum number of assignments with one combination index of 10 bits is 8. If more than 8 assignments are needed then another combination index is used to partition the last partition in the previous combination index.
- For example, to assign 9 users with a combination index corresponding to CI(1,1,1,2,2,3,4,4,6), two combination indices can be used.
  - The first combination index corresponds to 8 partitions of 24 available resources $CI_{24}(1,1,1,2,2,3,4,10)$
  - The second combination index, which partitions the last partition in the previous CI (10 resource units), corresponds to $CI_{10}(4,6)$.

Content of Multicast Control Segment for a Localized Zone

- For localized channel assignments a permutation index (PI) can be used instead of a combination index to indicate the sub-bands assigned to different users.
- The permutation index represents the number of contiguous sub-bands that are assigned to each user. Non-contiguous sub-bands can be assigned to a mobile with separate assignment messages.
- The mobiles are assigned in order of their assigned sub-bands.
- If the number of assignments is k and the total number of sub-bands is N_s then the permutation index represents a vector $(n_1, n_2, \ldots, n_k)$, where $\Sigma n_i = N_s$ and $n_i > 0$, $i = 1, 2, \ldots, k$.
- For example, if the permutation index represents the vector (n_1, n_2, n_3) then the first mobile is assigned the first n_1 sub-bands, the second mobile is assigned the next n_2 sub-bands and the third mobile is assigned the next n_3 sub-bands.
- If the number of sub-bands is 8 and the maximum number of assignments is 8 then the number of permutations is 128 (7 bits)
- In general, if there are N sub-bands with up to N assignments then the number of permutations is 2^{N-1} and therefore N-1 bits are required for the permutation index.

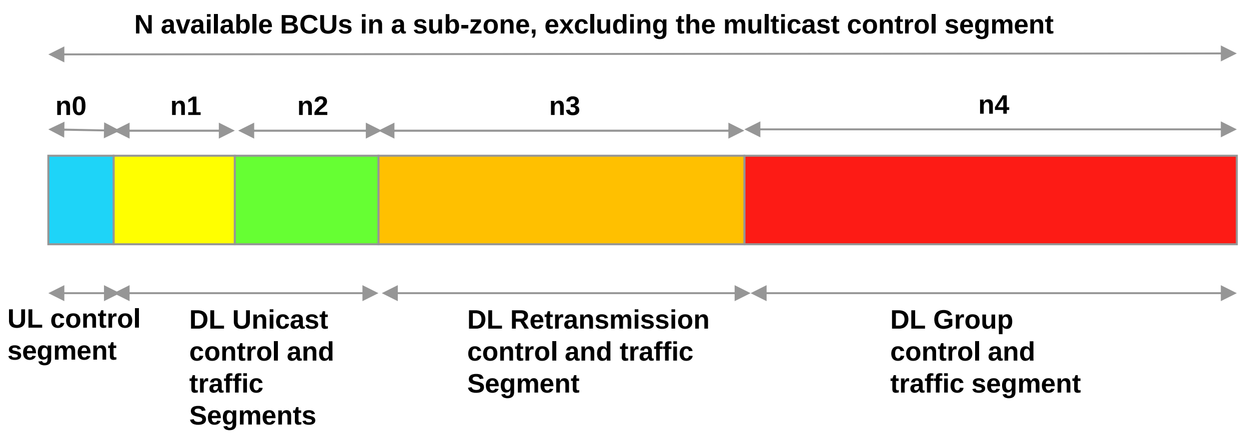
Example Using the Permutation Index

- The table below shows an example of a permutation index look-up table for the case where there are 4 sub-bands.
- In this case, there are a total of 8 permutations and only 3 bits are required to signal the PI.

Permutation Index	Number of Assignments	Sub-band allocations
0	1	4
1	2	1,3
2	2	2,2
3	2	3,1
4	3	1,1,2
5	3	1,2,1
6	3	2,1,1
7	4	1,1,1,1

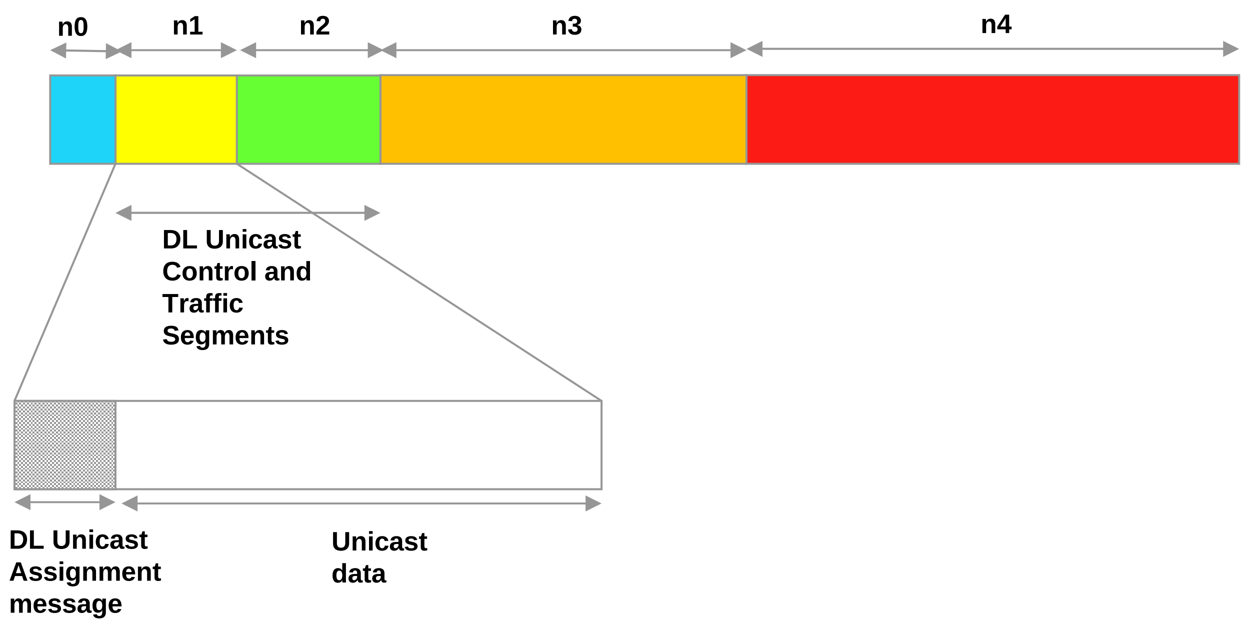
Non-Persistent Resource Assignment Within a Diversity Zone

- The ordered list of available resources within persistent and non-persistent sub-zones are divided into several segments.
- The segments are ordered in increasing partition size.
- The different types of segments include
  - An UL control segment,
  - DL Unicast control and traffic segment,
  - DL Retransmission control and traffic segment in the case resource adaptive synchronous HARQ is used (for asynchronous, this segment is not present since asynchronous HARQ retransmission can be assigned by the unicast control and traffic segment)
  - DL Group control and traffic segment.
- The diagram below is signalled with a combination index that indicates how the N resources are divided into 5 partitions of lengths n0, n1, n2, n3, n4.



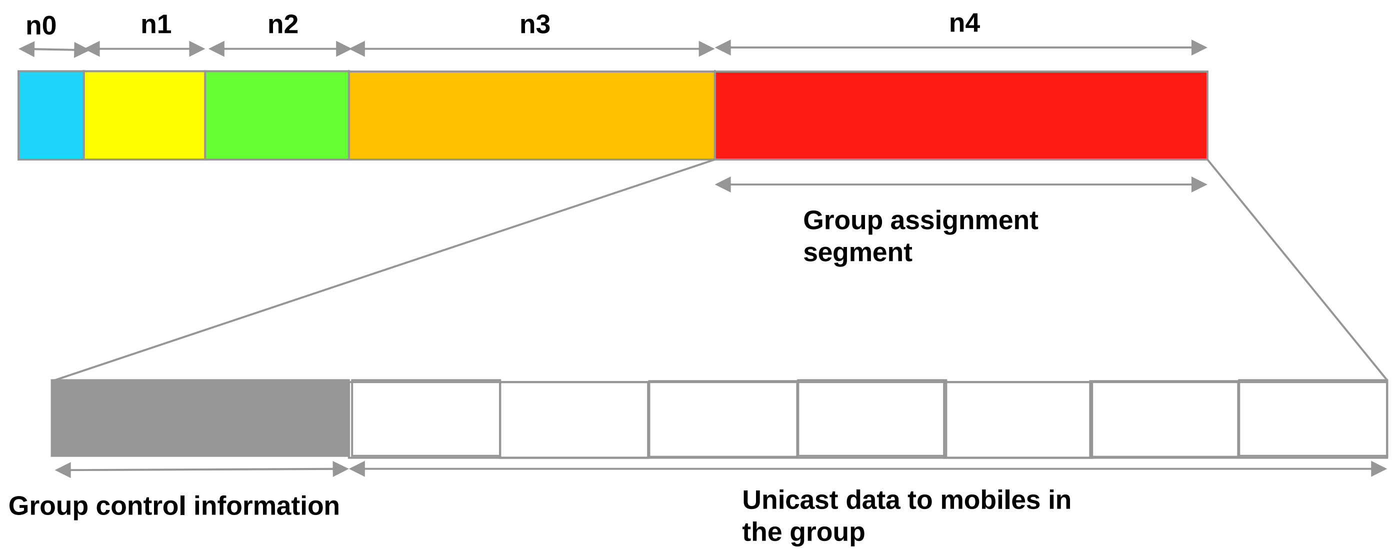
Unicast Control and Traffic Segment

- The unicast control and traffic segment consists of one unicast assignment. There can be multiple unicast control and traffic segments.
- The unicast message is scrambled by the user ID of the intended user.
- The length of the message depends on the type of assignment. There are a limited number of message lengths (e.g. 2). The mobiles use blind detection to decode the message.
- Each unicast message is followed by the data for the intended user.
- The length of the unicast message can be a fraction of a BCU.



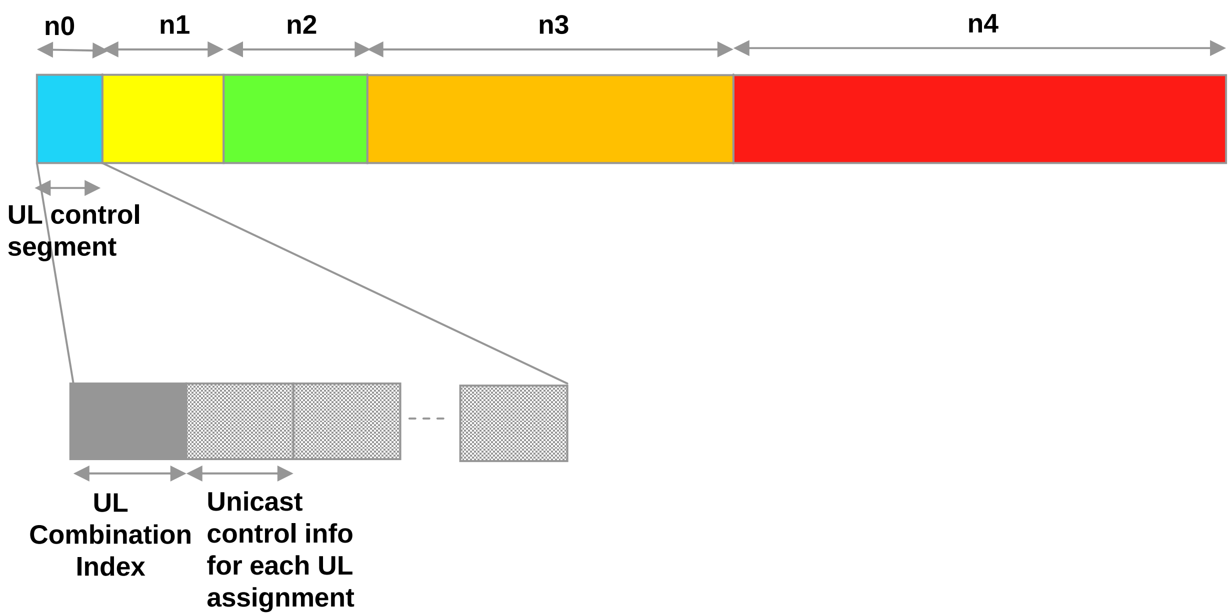
Group Control and Traffic Segment

- The group control and traffic segment is used for real time traffic such as VoIP. There can be multiple group assignment segments (see VoIP contribution C802.16m-08/177 for details).
- The control channel for the group assignment segment is a multicast assignment message and is located within the resources allocated for the group assignment segment.
- To identify the group assignment segment, the group assignment message is scrambled by the group ID.
- The message length is known to all the mobiles in the group.



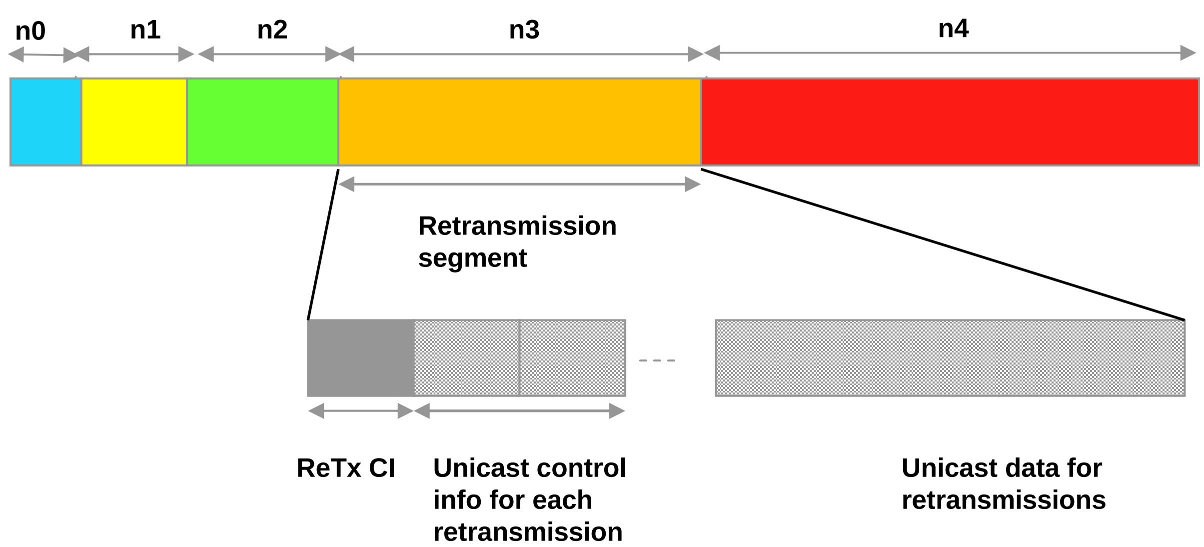
UL Control Segment

- Multiple users are assigned resources using an UL CI. This is then followed by unicast assignment information for each user.
- The unicast information is a fixed length and is decoded by each user sequentially until the mobile finds its UL unicast assignment message.
- The unicast information contains the assigned MCS and it is scrambled by the user ID of the intended user.
- The group UL assignment messages are signaled after the unicast UL assignments. The group assignment message length is an integer multiple of the unicast message and it is scrambled by the group ID (see VoIP contribution C802.16m-08/177).



Retransmission Segment

- The retransmission segment is only required when resource adaptive synchronous HARQ is used.
- In resource adaptive synchronous HARQ, the retransmissions occur at a pre-determined time and at the same MCS entry as the original transmission.
- Only the resource location is adapted.
- The retransmission segment is partitioned using a combination index, which is signaled at the beginning of the retransmission segment.
- The retransmission combination index is scrambled by a unique code that identifies the retransmission segment.
- The retransmission CI is then followed by a unicast message for each retransmission. The unicast message consists of the resource ID of the transmission on the previous interlace.



Persistent Resource Assignment

- Persistent resource assignment can be used for low geometry users for traffic such as VoIP
- Persistent sub-zone allows multiplexing of persistent resource and non-persistent assignments through the RAB
- Details of the persistent sub-zone and RAB are given in the VoIP contribution C802.16m-08/177

Control Channel Overhead Comparison (1/3)

- The overhead for the proposed control channel design is compared with the WiMAX reference system and with UMB for two cases
  - Case 1: Simple non-MIMO assignments (eg. STTD R1/R2).
  - Case 2: Single user MCW MIMO assignment with 4 layers.
- Only overhead due to resource allocation is included. Other control overhead such as DL ACK channel and power control channel are not included in the overhead calculations.
- Assumptions for WiMAX reference system overhead calculations
  - FCH is modeled.
  - The map is transmitted using QPSK ½, with repetition = 6. Three sub-maps are transmitted using QPSK ½ with repetition = 4, 2, and 1.
  - The user distributions for the MAP and the 3 sub-maps is 0.07, 0.20, 28, 0.45, respectively.
- Assumptions for UMB overhead calculations
  - The unicast messages in the F-SCCH are 39 bits long (including CRC)
  - One F-SCCH message is needed for each assignment in case 1.
  - Two F-SCCH messages are needed for each assignment in case 2.
  - The F-SCCH is transmitted using QPSK 1/3.

Control Channel Overhead Comparison (2/3)

- Assumptions for Nortel's proposal overhead calculations
  - The multicast control segment consists of a 10 bit combination index and a CRC of 6 bits.
  - The non-MIMO assignments in case 1 are 22 bits including CRC.
  - The MIMO assignments in case 2 are 38 bits including CRC.
  - The Multicast control segment is transmitted using QPSK 1/3 with repetition = 2 and the unicast messages are transmitted using QPSK 1/3.
  - There are 24 BCUs in a 10 MHz. One BCU is used to transmit the CI and DL ACK channel and other DL control channels. There are 23 available BCUs for DL assignments.

Control Channel Overhead Comparison (3/3)

Number of DL Non-MIMO Assignments	WiMAX Reference System Overhead (%)	UMB Overhead (%)	Nortel's Proposal Overhead (%)
1	9.82	1.67	0.78
5	10.71	5.00	2.05
10	11.83	8.33	3.65

Number of DL MIMO Assignments (4 layers)	WiMAX Reference System Overhead (%)	UMB Overhead (%)	Nortel's Proposal Overhead (%)
1	9.82	1.67	1.01
5	10.71	8.33	3.21
10	11.83	16.67	5.96

Comparison of Blind Decoding Complexity

- In LTE, the number of blind decoding attempts as provided in contribution R1-081101
  - For common search space is ~10
  - For UE specific search space is ~30
  - The total is ~40 blind decoding attempts every TTI, which is equivalent to 2 Mbps.
- The number of blind decoding attempts in the Nortel proposal
  - Up to 2 attempts for different unicast message types per partition.
  - Since the expected number of partitions < 10, the total number of blind decoding attempts < 20 < LTE.

Summary

- In summary, the proposed control channel design shows a significant improvement in control overhead over both the WiMAX reference system as well as UMB.
- The new design minimizes both power and bandwidth overhead.
- The lower overhead is attributed to following
  - Using a combination index rather than a channelization tree
    - More flexibility (no restrictions in the number of resources that can be assigned)
    - Lower overhead since the node ID does not have to be signaled in each assignment.
  - Taking advantage of multicast control and unicast control
    - Multicast control is used to signal common information that is needed by all the assigned users and
    - Unicast control is used to signal user specific information.
  - By combining the unicast control with the data, the resource granularity for the control is lower
    - For unicast control, the granularity is to the unit of a single tone
    - For group control, the granularity is to the unit of RBs.