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Abstract	CQI feedback framework - Details
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CQI Feedback Framework – Details

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1. Introduction and Background

In IEEE C802.16m-08/391 we proposed the CQI feedback framework and the SDD text. In IEEE C80216mUL_ctrl-08/016, we updated the SDD text on the CQI feedback framework part of the updated fast feedback control channel. In this contribution, we provide more details of the proposal and support the relevant text in the latest version of the SDD text on UL control channel [3].

2. Primary/Secondary Feedback Reporting Protocol

2.1 Motivation for 2-level Primary/Secondary fast feedback channel design

In 802.16e system, fast feedback channel only provides fixed robust rate for CQI transmission, which is designed in such a way that the same efficiency and error protection ability is provided to SS despite their different channel conditions.

In 802.16m, advanced features, such as frequency selective scheduling and MU/SU-MIMO, are desirable in order to yield higher system spectrum efficiency. Our initial analysis shows the number of feedback bits required per CQI per user can be as high as 80 bits per frame to support advanced features such as MU-MIMO (please refer to appendix A for more details). It is not possible to send so much of CQI overhead bits using the single fast feedback channel with fixed rate as mentioned above. With only a single fast feedback channel with fixed rate, multiple channels have to be allocated to carry such payload which will either increase overhead or require the information to be sent over a longer period of time with increased latency. Thus, it is imperative to design fast feedback channel that could carry over more information bits with higher efficiency.

As mentioned above, feedback payload in 16m can vary significantly depending on different traffic models/features. It is desirable to design two structures optimized for low and high feedback payload separately. Additionally, the high payload feedback is based on the user channel/traffic condition. It is desirable to support high payload feedback only on demand and to support coarse link adaptation to further improve efficiency and capacity on the high payload feedback channel. The coarse link adaptation will be based on user location/channel condition to improve feedback efficiency. With this design, center users can take advantages of their high SINR and transmit CQIs at high rates with an improved efficiency.

In order to efficiently support frequency selective scheduling and MU/SU-MIMO for the users, especially those with good channel quality, and to keep the UL feedback overhead restrained within the range of 10-15%, we propose to support:

(1) The separation between the primary (wideband CQI reports with fixed rate) and secondary (sub-band CQI reports with adaptive rate) UL fast feedback channel;

(2) Link adaptation on the secondary UL fast feedback channel.

The primary fast feedback channel is designed to support basic feedback (similar to legacy CQICH in 16e) with improved reliability, while the second one is designed to support advanced features with better efficiency with adaptive rates.

This also allows flexibility for independent channel design in order to optimize each channel' performance (for example, the two channel might achieve optimal performance under different permutation modes).

2.2 Primary/Secondary fast feedback channel protocol

Primary fast feedback channel is designed to cover all users who need to feedback CQI in UL. BS allocates resource for primary fast feedback channel and specifies the feedback frequency based on each individual user's channel variation characteristics. This information is sent to UE to regulate its CQI feedback behavior. BS may use non-coherent detection to detect signals in primary fast feedback channel to ensure coverage.

As mentioned in section 2.1, adaptive rate is desired in order to support advanced features (such as to support FSS and MU/SU MIMO etc.) in 16m. To guarantee robust transmission while maximizing throughput of secondary fast feedback channel, link adaptation is supported on it and it will be coarse based on long term statistics and margin will be added when doing adaptation to guarantee reliability.

Secondary fast feedback channel targets to cover users with localized resource allocation at downlink that requires to feedback more CQI to support features such as FSS, MIMO etc., while users with very poor channel quality might not achieve meaningful gain feeding more CQI using secondary fast feedback channel. Per request from MS, BS will decide whether to allocate secondary fast feedback channel, when to allocate, the amount of resource and corresponding index, transmission frequency, rate, and relay these information to SS. The receiver detection in BS on secondary fast feedback channel can be coherent or non-coherent depending on selected MCS rate per user's channel variation.

As shown in Figure 1, primary fast feedback channel supports each user to feedback CQIs periodically in multiple of frames. Users' CQI feedback on secondary fast feedback control channel may be more frequent than that on primary fast feedback control channel. Secondary fast feedback channel's allocation can be event driven depending on the user's traffic condition and channel variation.

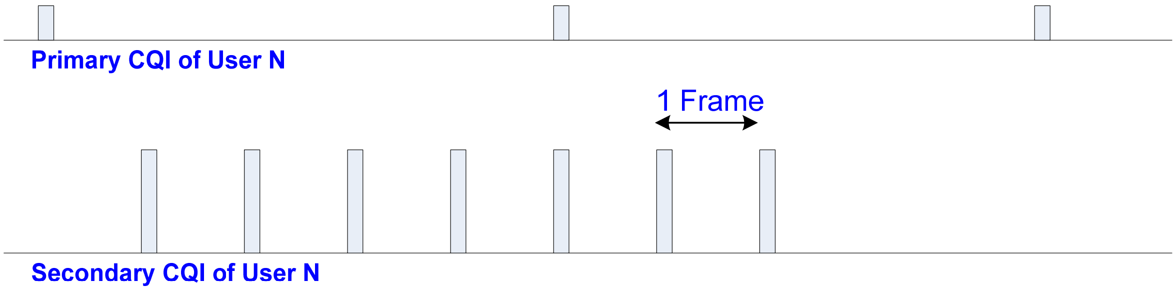


Figure 1 An example of periodicity and frequency of primary and secondary fast feedback channels in time domain

Additionally, primary fast feedback channel can provide a reference for power control. This reference can be used for power controlling both data channel and secondary fast feedback channel. Secondary fast feedback channel requires UL power control to help UE to achieve a minimum SINR so that the lowest MCS level can be supported.

2.3 Multiplexing with other control channels and data channels

Primary and secondary fast feedback channels will be designed as different physical channels because it requires different structures, pilot patterns, modulations and coding etc. The major reason to have two fast feedback channels is to efficiently carry various CQI/CSI/adaptation information while also be able to cover users with very bad channel conditions. The primary fast feedback channel is the most robust one to support all the users, but it suffers from low capacity, hence only intends for carrying basic CQI information. Second fast feedback channel is designed to have high capacity to carry more information efficiently with link adaptation.

The system will allocate 2 physical resource regions, which can be continuous or discontinuous, for primary and secondary channels separately and total BW specified for them can be adjusted slowly based on traffic condition and user distribution variations. In each sub-frame, there should be no more than one instance of primary fast feedback control channel and no more than one instance of secondary fast feedback control channel. The primary and secondary fast feedback control channels are FDM'ed with other control and data channels, and there is no need for TDM or CDM within a sub-frame.

Within primary or secondary CQI allocation, there are several possibilities to multiplex multiple users, among which 2 typical ones are to allocate different users with frequency orthogonality, or with code orthogonality. As we know, the latter approach has several drawbacks as listed below:

1) It provides fixed rate and it is difficult to do link adaptation without incurring significant complexity increase.
2) It suffers a lot from performance loss due to inter-user interference.
3) Additional power control scheme different from the one used in traffic channel is needed in order to well control the interference environment since it is basically a self-interfered system

4) BS still needs to consider how to allocate different users in each CDM channel and how to allocate codes to each user. Thus there is no scheduling advantage over frequency orthogonality based approach.
5) It has flexibility advantage of supporting different number of users but this is also its disadvantage because the interference will becomes more severe when more users are supported.

But above drawbacks do not exist if users are FDMed. Additionally, depending on specific tile size used in fast feedback channel, TDM may be also desirable to guarantee the best usage of resources in each CQI region. Thus we propose that multiple users' primary CQI allocations have frequency/time orthogonality, and multiple users' secondary CQI allocations have frequency/time orthogonalilty.

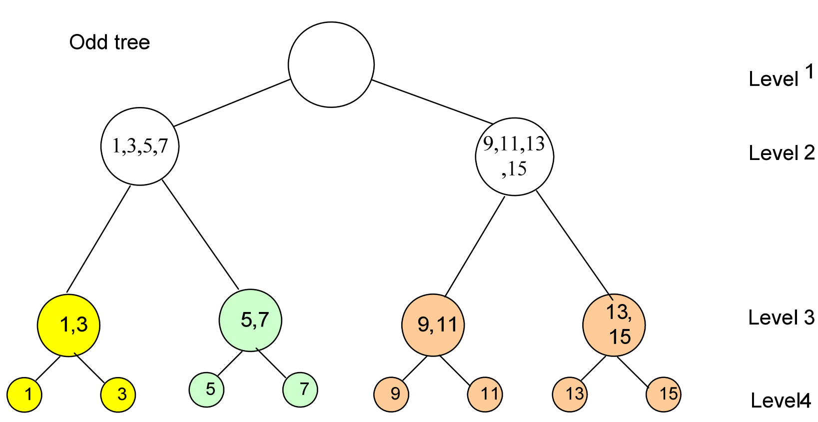
3. Frequency Selective Scheduling and CQI Feedback Compression

Scheduling gain would be optimal when the resource block granularity is same as the CQI feedback granularity. E.g., when there are 64 resource blocks the CQI granularity is also on the 64 resource blocks. If best M of the resource blocks to be feedback with a bitmap as in the 16e case, it would require 64 bit bitmap. In this ideal case, the CQI feedback overhead will be high.

On the other hand, for MU/SU-MIMO it is observed that the performance deteriorates when combining several resource blocks into a band and receive only the average CQI value of the band instead of the CQI values of individual resource blocks.

To reduce the CQI feedback overhead we can support multiple tree types and hierarchical trees.

Multiple tree types can provide several meaningful sub-trees. For example, odd and even trees are supported in 16e. Odd and even trees are kind of blind sub-trees that do not take into account the need to report on consecutive bands. 16m should support various meaningful sub-trees. In this case, the mobile station reports not on the whole tree but on the specific sub-tree. This mechanism reduces the CQI feedback overhead while restricting the selecting at the mobile station. Examples of tree types are illustrated in Figure 2.



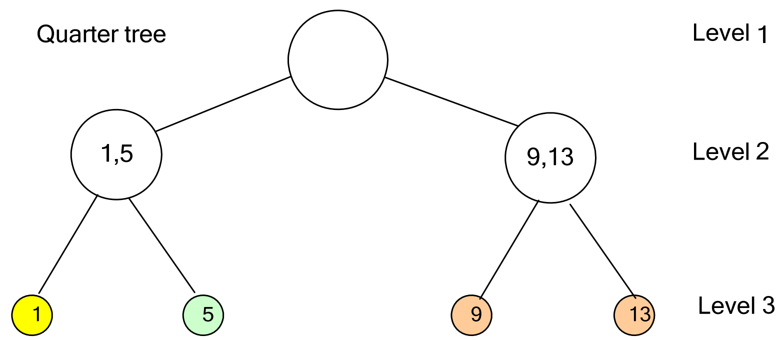


Figure 2: Example of (a) an Odd Tree and (b) A Quarter Tree

When the channel is flat across a certain frequency band higher layer node of the hierarchical tree can be chosen. This mechanism reduces the overhead by taking advantage of the flat channel and sending the average value of the flat band. In this method either more reports can be mad available at the base station for better scheduling gain or the feedback overhead can be reduced. An example of the hierarchical tree is illustrated in Figure 3.

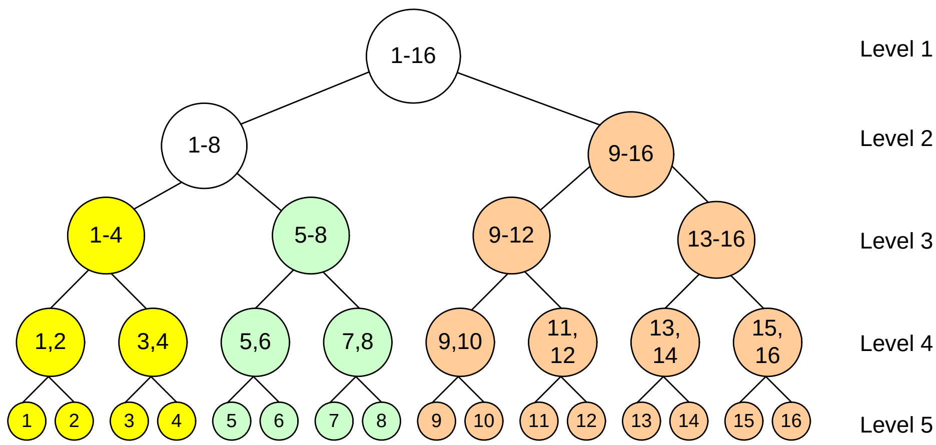


Figure 3: An example of a hierarchical tree representation

Reporting the full CQI for the entire band is not possible since there are two many resource blocks/bands and possibly users. The overhead needs to be limited for uplink efficiency. There are several compression techniques possible in frequency, time and space domains. Techniques should support mechanisms to optimize reporting CQI granularity, CQI amount, CQI indexing, and CQI value.

The tree types and hierarchical trees discussed in the previous section are few examples of optimizing CQI feedback. The higher the CQI feedback amount at the base station the higher the scheduling gain, but also the higher the uplink overhead. CQI amount depends on the number of users in the system and the traffic characteristics of the user. CQI indexing is a mechanism to efficiently indicating the reporting resource blocks/bands along with the CQI values. An average CQI value may result in higher packet error rate and not suitable for MIMO performance, on the other hand a min CQI value may result in lower throughput. Compression techniques should consider all these issues.

4. Conclusions

This document supports the latest version of the SDD text [3] on UL control channel.

5. References

[1] IEEE Std. 802.16e-2005, IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, and P802.16Rev2/D3 (February 2008).

[2] WiMAX Forum™ Mobile System Profile, Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02), http://www.wimaxforum.org/technology/documents.

[3] IEEE 802.16m-08/003r4, "The Draft IEEE 802.16m System Description Document"

[4] IEEE C802.16m-08/391, "proposal for IEEE 802.16m CQI Feedback Framework"

[5] IEEE C80216m-08/004r1 EMD.

[6] IEEE C80216mUL_ctrl-08/016, "CQI Feedback Framework – Details"

6. Appendix A: amount of CQI feedback analysis for Closed Loop MU-MIMO

This appendix provides an example analysis on amount of CQI feedback needed for 2x2 Closed Loop MU-MIMO. It assumes that best-M based CQI feedback with tree based indexing method is used and each user needs to report best-M CQIs among 12 sub-bands (assuming RB size of 18x6 and each sub-band includes 4 RBs). For simplicity, only CINR (4bits, 2bits per differential CINR) and MIMO pre-coding codebook (3bits for 2x2) are considered in this calculation. Thus, total CQI bits of 2 streams per user will be: $4*M*2+3*M+2*\log2(C(12,M))$, where

1) 1st stream: $4 * M+3 *M + \log2(C(12,M))$

2) 2nd stream: $4* M + \log2(C(12,M))$

Here, $C(12, M)$ stands for the permutation and combination of $(12, M)$.

In best-M based feedback method, in order to guarantee balanced CQI reporting among whole frequency band, 'M' will increase when there is smaller number of users and decrease when number of users becomes larger, thus CQI bits per user changes depending on how many users are transmitting with closed loop MU-MIMO.

As shown in table 6-1, with the method of individual CQI with tree based indexing,

1) Bits per CQI per user can be as high as 86bits when there are only 5 users

2) Total CQI bits for all users can be as high as 360bits when there are 20 users and each user feeds back 1 CQI per 2 frames.

Table 6-1 Amount of CQI feedback for Closed Loop MU-MIMO

Method	User number	M (best-M)	bits per CQI per user	Total CQI bits (each user feedback 1 CQI per 2 frames)
Individual CQI plus indexing	5	6	86 bits [CQI: 4*6*2 + 3*6 = 66bits] [Indexing: 2 * c(12,6): 20bits]	215 bits
	10	3	49bits [CQI: 4*3*2 +3*3 = 33bits] [Indexing: 2 * c(12,3): 16bits]	245 bits
	20	2	36 bits [CQI: 4*2*2 +3*2 = 22bits] [Indexing: 2 * c(12,2): 14bits]	360 bits
Differential CQI plus indexing (1 average CQI with 4bits + 2 bits for differential)	5	6	66bits [CQI: 4+2x6x2 + 3x6 = 46bits] [Indexing: 2 x c(12, 6): 20bits]	165 bits
	10	3	41bits [CQI: 4 + 2x3x2 + 3x3 = 25bits] [Indexing: 2 x c(12,3): 16bits]	205 bits
	20	2	32 bits [CQI: 4 + 2x2x2 +3x2 = 18bits] [Indexing: 2 x c(12,2): 14bits]	320 bits