Cross Layer Scheduling for Mixed Services in Multiuser MIMO OFDM system

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***Abstract*-For wideband Multiple Input and Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) wireless suystem, the fading selecivity in spatial-temporal-frequency domain and the variable network load and interference put a constraint on the system design. The traditional layered protocol design can't adapt to these variance and results in low transmission efficiency. In this paper, a cross layer framework for multiuser Radio Resource Mangement (RRM) in MIMO and OFDM system is proposed to optimise the system performance. Based on this, two cross layer scheduling algorithms based on Modified Proportional Fairness (MPF) and Quality Guaranteed (QG) priority function are designed for mixed Real Time (RT) and Non-Real Time (NRT) services in multiuser MIMO OFDM system. From the simulation results, QG&MPF has much better performance than M2PF. For 2×4 MIMO case, QG&MPF can support 40 RT user and 40 NRT users in 10MHz bandwidth simultaneously, and the system throughput of QG&MPF can approach 32Mbps; while M2PF can only support 15 RT users and 15 NRT users, and the system throughput is about 11.5Mbps.**

Key words: Cross Layer, Mixed Services, MIMO, OFDM

I. INTRODUCTION

Since the standard work on the evolved 3G has almost been finished in 3GPP and 3GPP, ITU-R has started its work on next generation mobile communication system, which is named as IMT-Advanced. IMT-Advanced system is expected to be designed as a user centric system, which can provide any service for anybody at anytime and anywhere needed [1]. According to the literatures [2][3], the peak data rate of IMT-Advanced will be 100Mbps~1Gbps in 20~100MHz bandwidth, and the average spectrum efficiency will be 2.1/1.5bps/Hz in downlink/uplink. Based on the researches in [2][3]. MIMO and OFDM have the potential to meet such requirements. According to the prediction of ITU-R, the spectrum requirement for IMT-Advanced is about 2GHz. But only about 428 MHz spectrums (some of them are only available regionally in the world) have been allocated for IMT-Advanced in WRC 2007. To meet the requirement of the development of the wireless industry and market, much higher spectrum efficiency is expected from IMT-Advanced system.

However, the characteristic of the cellular system put a challenge on the IMT-Advanced system design. In a cellular system, the channel property varies fast and the dynamical range of the Signal-to-Interference Ratio (SIR) is very large, e.g. from -5dB~30dB. On the other hand, the variance of the user data rate is large, e.g. from several Kbps to 1Gbps, and the Quality of Service (QoS) also varies so much. To guarantee the QoS of the different users admitted in the system and provide high spectrum efficiency, the system protocol and algorithms must be designed carefully and efficiently.

In traditional communication system, the protocol of the air interface is designed as simple layered style, where the operation and design of every layer is independently and the interface between the neighboring layers is static [4], and the service for one layer can only be provided by its lower layers. This architecture has succeeded so much in the cable communication industry since it can simplify the system design and driven its application and spread over the world. However, this architecture can't adapt to the randomly variable spatial-temporal-frequency characteristics of the wireless wideband MIMO channel and the variable network load and interference in the system, and results in low transmission efficiency.

To improve the transmission efficiency of the wideband MIMO system, some cross layer protocol design [4] [5] [6] for wideband wireless system is investigated. In cross layer design, the constrains on the design of every layer is changed, where the QoS Information (QoSI), Queue Information (QI), Channel State Information (CSI), the Network load and interference information can be shared and exchanged among different layers, but not only between neighboring layers. Based on this cross layer architecture, the multiuser diversity gain can be achieved potentially in spatial-temporal-frequency domain jointly by multiuser scheduling to maximize the system throughput with guaranteed QoS.

In this paper, a framework of cross layer RRM for multiuser MIMO OFDM is proposed. Based on this, two advanced scheduling algorithms, M2PF, and QG&MPF can obtain the high system throughput with the guaranteed QoS in a MIMO OFDM system with mixed service. Since M2PF usually allocate the resource for RT service in higher priority, the throughput improvement provided by multiuser diversity gain of NRT users are sacrificed to guarantee the data rate of RT services. So QG&MPF achieves much better performance than M2PF. For 2×4 MIMO case, QG&MPF can support 40 RT user and 40 NRT users in 10MHz bandwidth simultaneously, and the system throughput of QG&MPF can approach 32Mbps; while M2PF can only support 15 RT users and 15 NRT users, and the system throughput is about 11.5Mbps.

II. FRAMEWORK OF CROSS LAYER SCHEDULING

In MIMO OFDM based IMT-Advanced system, the function of RRM is to schedule the user packets to the system radio resource unit, decide the multiuser multiplexing and spatial multiplexing policy; decide the transmission power and modulation&coding scheme for individual users and resource units; admit the new users, avoid the system congestion according the network load and interference condition and manage the user transmission power and mobility.

To achieve the target of the IMT-Advanced system optimization, the philosophy of cross layer design is necessary for the IMT-Advanced system design. In this paper, a novel logical framework of cross layer RRM is proposed as Figure 1. The QoSI, QI, CSI and Network load and interference information can be exchanged and shared between RRM module and the other layers, and thus the optimization on the multiuser RRM can be executed to obtain multiuser diversity gain and guarantee the link reliability and QoS, maximize the system throughput and keep the system reliable. The following functions can be performed among RRM and different layers:

- The measured CSI, measured Interference, resource allocation information and Adaptive Modulation and Coding (AMC) information of Physical layer (PHY) can be shared and exchanged with RRM.
- RRM can share and exchange the measured QoS, QoS mapping information, QI and HARQ information with Media Access Control layer (MAC).
- RRM can obtain the network load and cell load information from network layer.

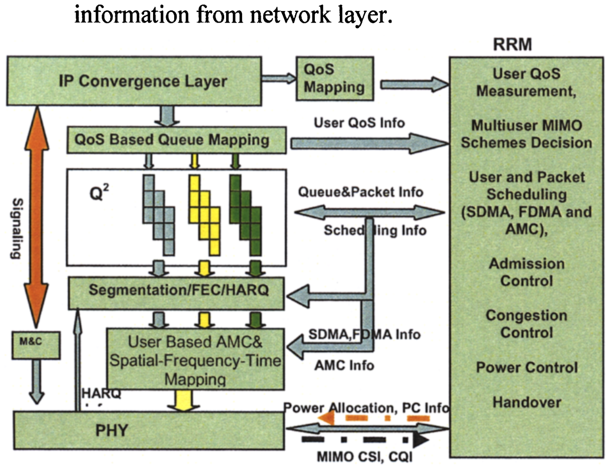

Figure 1 Cross layer RRM framework

The function of the individual module in the framework is described as below.

IP Convergence Layer: Complete the transformation from IP protocols to air interface, which may include IP head compression and de-compression, ciphering.

QoS based Queue mapping: Mapping the different user's packet to different Queue with different QoS predefined according to the negotiated QoS when the service is admitted.

Q2: Maintain the queue and execute the packet scheduling order from RRM. The maintenances of the queue include packet storing and deletion, time stamp of the packet arrival and the waiting time. If the waiting time of the real time service packet exceeds the constraint, the packet is deleted from the queue.

Segmentation/FEC/HARQ: perform the segmentation and de-segmentation, forward error correction coding of the packets; Choose the ARQ mode, the redundancy version and the modulation and coding scheme according the transmission condition; backup the scheduled packets and report the packet loss information.

User Based AMC & data mapping in spatial and frequency domain: according to the scheduling results, perform AMC and data mapping in spatial frequency domain for individual users. The reverse operation is done at the receiver, and judge if the packet is received right, and report the status to the HARQ module.

PHY: perform the signal transmission and detection; respond to the physical control signaling, e.g. power adjustment according to the power control order; measure the CSI, interference and network load and so on.

QoS mapping: According to the admitted user, inform the RRM the corresponding QoS specification.

RRM: The function of RRM module include user QoS measurement, selection of multiuser MIMO transmission policy, user and packet scheduling, admission control, congestion control, and power control. The sub-functions are described below.

User QoS measurement: measure the current user QoS according to the QI, user QoS specification. The measurement results may trigger the scheduling procedure. For RT service, the metrics for measurement include packet delay, delay jitter and packet loss ratio; for NRT service, the metrics include minimum data rate required and packet loss ratio.

Selection of Multiuser MIMO transmission policy: based on different MIMO channel characteristic, SNR distribution and CSI available, different multiuser MIMO schemes may be selected. The different range of the CSI may also lead to different multiuser MIMO scheme. So the system should select the efficient multiuser MIMO scheme to maximize the system throughput statistically based on the UE QoS, environment characteristic, interference condition and the user packet queue status.

User and packet scheduling: according to the QoS measurement, CSI, QSI, the scheduler decides the resource allocation and MCS for different users for next duration of the transmission to maximize the system throughput and guarantee the user fairness by exploiting the multiuser diversity gain in spatial-temporal-frequency domain and multiplexing gain in spatial domain..

Power control: According to the distance between the base station and UE, allocates and adjusts the transmit power to guarantee the link reliability and capacity with lowest power consumption.

III. CROSS LAYER MULTIUSER SCHEDULING

Zero Forcing Beamforming (ZFB) [6] can achieve multiuser MIMO capacity by multiplexing several users' data on the same radio resource without interfering each other. In this paper, it is considered as the multiuser MIMO scheme. For MIMO OFDM system, the MIMO channel on subcarrier n can be expressed as $\mathbf{H}_{i,n}$. Assume the general multiuser MIMO channel matrix is expressed as $\hat{\mathbf{H}}_n = [\mathbf{H}_{1,n} \ \ldots \ \mathbf{H}_{i,n} \ \ldots \ \mathbf{H}_{K,n}]$, where $\mathbf{H}_{i,n}$ is the MIMO channel matrix of user i with $M_T \times M_R$ dimension, and M_T, M_R are the transmitter and receiver antenna number respectively. By antenna selection and multiuser scheduling, the multiuser spatial diversity gain can be achieved. The antenna selection can be performed as the opt and subopt algorithms proposed in [7].

In this section, based on the cross layer RRM framework proposed in section II, two scheduling algorithms for mixed RT and NRT services based on channel and queue aware are compared for multiuser MIMO OFDMA system in downlink. For M2PF algorithm [8], the priority of both RT and NRT service is calculated by the MPF [8] priority function definition. For QG&MPF algorithm [8], the priorities of RT and NRT services are calculated respectively by QG and MPF priority function.

- **MPF for NRT**

For NRT service, the MPF priority function is defined as:

$$\Pr_n^k(t) = \frac{R_n^k(t)}{\bar{R}_k(t)} \times \exp\left\{\frac{r_{\min} - \bar{r}_k}{r_{\min}}\right\} \quad (1)$$

Where $R_n^k(t)$ is the averaged transmission capability of user k on subcarrier n, $\bar{r}_k$ is the averaged user data rate since the service setup, $r_{\min}$ is the required minimum data rate, $\bar{R}_k(t)$ is the average data rate of user k.

For RT service, the MPF and QG priority function are defined as follow.

- **MPF for RT**

$$\Pr_n^k(t) = \frac{R_n^k(t)}{\bar{R}_k(t)} \times \frac{Buff\_Len}{r_S} \times \frac{P_{drop} + P_{sent}}{P_{sent}} \quad (2)$$

Where $Buff\_Len$ is the buffer length of user k; r_S is the service data rate, P_{drop} is the number of the dropped packets which exceeds the maximum packet delay, and P_{sent} is the number of the packets transmitted.

- **QG**

For real time service, the service has strict constraint on delay, but permits some packet drop ratio. To maximize the user number serving by the system, system may permit every user has a small packet drop ratio less than the pre-defined one. So we proposed a modified scheduling algorithm (QG) for real time service, the user priority is defined as:

$$\Pr_n^k = \frac{\hat{R}_{k,n}(t)}{\hat{R}_k} \times f\left(PLR_k, W_k(t)\right) \quad (3)$$

Where,

$$f(PLR_i, W_i(t)) = \begin{cases} 10^{W_i(t)/W_{Max}} \times 10^{PLR_i/PLR_{Max}}, \\ \quad if\ PLR_{Max} \geq PLR_i \\ 10^{W_i(t)/W_{Max}} \times 10^{(2PLR_{Max} - PLR_i)/PLR_{Max}}, \\ \quad if\ PLR_{Max} < PLR_i \end{cases} \quad (4)$$

Where $W_i(t)$ is the maximum packet delay in queue, W_{max} is the permitted maximum packet delay for every service, $PLR_i(t)$ is the current packet loss ratio, PLR_{max} is the permitted maximum packet loss ratio.

When PLR_i is small, the priority value of QG is less than that of Proportional Fairness; when PLR_i approaches PLR_{Max}, the priority increases fast; when PLR_i exceeds PLR_{Max}, the priority is decreased to avoid wasting on the limited radio resource by the user with bad channel condition.

Based on the priority function defined above, the joint spatial-frequency channel and queue aware scheduling algorithm for multiuser MIMO OFDM system can be summed as following:

Step 1. On every subcarrier, the user priority of RT and NRT user is calculated according to the corresponding priority function defined. For M2PF algorithm, the priority of both RT and NRT service is calculated by the MPF priority function definition. For QG&MPF algorithm, the priorities of RT and NRT services are calculated respectively by QG and MPF priority function.

Step 2. On every subcarrier, M_T users with highest priority value are chosen to construct the user set U_n and general MIMO matrix $\hat{\mathbf{H}}_n = [\mathbf{H}_{1,n} \ \ldots \ \mathbf{H}_{i,n} \ \ldots \ \mathbf{H}_{K,n}]$.

Step 3: By antenna selection algorithm proposed in section II, and the spatial sub-channel gain $d_{k,n}$ for ZFB is calculated based on $\hat{\mathbf{H}}_n$, the proper MCS for every user is decided according to its SINR. The Opt, Subopt and Random algorithm [7] can be used to construct the spatial sub-channel for every subcarrier.

Step 4: Every user's averaged data rate $\hat{R}_i$ is updated as following:

$$\hat{R}_i = \begin{cases} (1-\alpha)\hat{R}_i + \alpha R_i, if\ user\ k\ is\ served. \\ (1-\alpha)\hat{R}_i, \qquad else \end{cases} \quad (5)$$

Where $0 < \alpha < 1$ is the forgetting factor.

$R_i = \sum_{n=1}^{N} r_{i,n}$ is the served data rate in current scheduling period, $r_{i,n}$ is the data rate on subcarrier n of user i. If subcarrier n is not allocated to user i, then $r_{i,n} = 0$.

IV. SIMULATION PARAMETER

In the simulation, MCS adopted is given in Table 1, the convolution coding are combined with QPSK, 16QAM to create 5 MCS. No H-ARQ is considered in link level simulation, but the chase combining is adopted in system level simulation. The suitable MCS is selected from the Table 1 to transmit data symbol on every subcarrier. The SNR threshold for MCS as Table 1 is obtained.

TABLE 1 THE MCS AND THE SNR THRESHOLD

MCS	Mod	Code Ratio	data bits	SNR threshold
1	QPSK	1/3	2/3	0.5dB
2	QPSK	1/2	1	3.7dB
3	QPSK	3/4	3/2	6.3dB
4	16QAM	1/2	2	10dB
5	16QAM	3/4	3	15.2dB

Every continuous 8 subcarriers are combined together as a basic Resource Block (RB), in which the same modulation and coding scheme is used for all subcarrier. One RB can be shared by different user according to the algorithms we proposed in section III. The power of the Node B is uniformly distributed on all spatial sub-channel and subcarriers.

The same frame structure as LCR TDD for LTE TDD [9] is adopted in our work. Every 10ms is divided into two sub frames, and the structure of the sub frame is as Figure 2. Every sub frame has 7 service slots and 3 special slots. The service slot length is 0.675ms, and 6 slots can be used to transmit data. In every service time slot, 9 OFDM symbols can be contained. The overhead of the control and reference, and the feedback delay and overhead of CSI are ignored in this paper in the simulation.

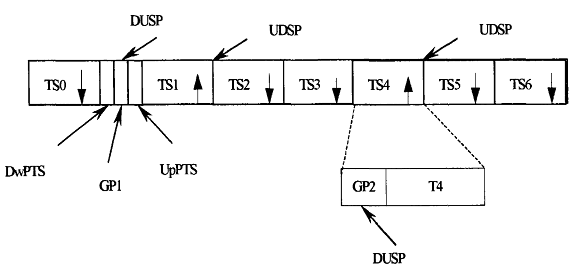

Figure 2 Frame structure of LTE TDD

The soft frequency reuse scheme is adopted and optimized as [6]. The 500kbit/s video traffic model is defined as Table 2. For none real time service, the full buffer data is assumed.

TABLE 2 TRAFFIC MODEL PARAMETERS

Video Stream model	Value
Inter-arrival time between the beginning of each video-frame	100ms
Number of video-packet in a frame	8
Video packet size	400byte
Inter-arrival between video-packets in a video frame	Truncated Pareto K=2.5 alpha = 1.2 M= 12.5ms
Video packet max delay time	200ms
Video average data rate Video minimum data rate	500kbit/s 128kbit/s
Video length	120s

If the user has 5% packets dropped during the communication, then the video user is regarded as unsatisfied.

The other system simulation parameters are as Table 3.

TABLE 3. SYSTEM PARAMETERS

Parameter		Assumption
Carrier Frequency		2GHz
Band width		10MHz
Sample Frequency		15.36 MHz
Sub-carrier spacing		15 kHz
CP length(μs/samples)		7.29/14
FFT Size		1024
Occupied Subcarriers number		601
Subcarrier Group number		75
Inter-site distance		2Km
Cell number		27 (9 clusters)
Distance-dependent path loss		L=128.1 + 37.6log10(R)
Shadowing standard deviation		8 dB
Correlation distance of Shadowing		50 m
Shadowing correlation	Between cells	0.5
	Between sectors	1.0
Penetration Loss		20dB
Channel model		Typical Urban (TU) PDP,SCM
Total BS TX power (Ptotal)		43dBm
Minimum distance between UE and cell		>= 35 meters
User data rate		2Mbps
HARQ		Chase combining

V. SIMULATION RESULTS

In this section, based on the cross layer RRM framework, the simulation results of the joint spatial-frequency scheduling based on M2PF and QG&MPF for mixed RT and NRT service are presented and RT and NRT service have the same user number indicated as the y-axis.

From Figure 5, the performance of QG&MPF is obviously better than M2PF. As the user number increase, multiple users compete the same resource, the difference between schedulers become obvious. The more the users, the larger the performance difference between QG&MPF and M2PF. For 2×4 MIMO, when the user number of the RT and NRT are both 30, the system throughput difference between M2PF and QG&MPF exceeds 100%. Since M2PF usually allocate the resource for RT service in higher priority, and the throughput improvement provided by multiuser diversity of NRT users are sacrificed to guarantee the data rate of RT services. So QG&MPF has much better performance than M2PF.

From Figure 3, for 2×4 MIMO case, QG&MPF can support 40 RT user and 40 NRT users in 10MHz bandwidth simultaneously, and the system throughput of QG&MPF can approach 32Mbps according to Figure 5, and spectrum efficiency is 3.2bps/Hz; while M2PF can only support 15

RT users and 15 NRT users in 10MHz bandwidth, and the system throughput is about 11.5Mbps; the spectrum efficiency is 1.15bps/Hz. Comparing the 2×4 MIMO case and 1×2 SIMO case, doubling the antennas at both end will double the user numbers supported in the system by QG&MPF.

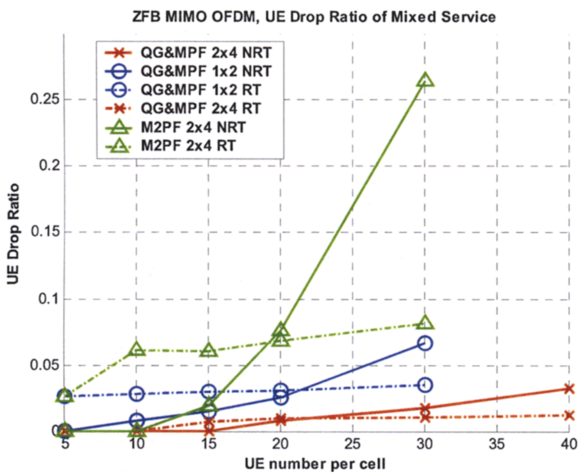

Figure 3. Mixed services: user number vs. drop ratio

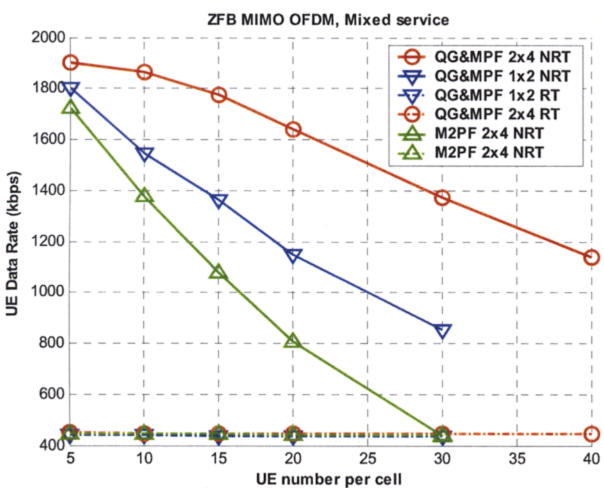

Figure 4. Mixed services: average user data rate vs. user number

From the Figure 4, the data rate of the RT services will not decrease obviously when the user numbers of both services increase. But the data rate of the NRT service decrease fast as the user number increase. So the scheduler proposed can guarantee the Quality of the RT service in higher priority. The drop ratio of the RT service varies little with the user number.

VI. Conclusion

For variance in the wireless channel characteristic and the network loading and interference, the layered protocol design will result in low transmission efficiency in MIMO OFDM system. In this paper, a novel cross layer RRM framework is proposed for multiuser MIMO OFDM system to adapt to the dynamical variance of the wireless channel and network loading and maximize the system throughput. Based on this framework, two joint spatial-frequency scheduling based on channel and queue aware for mixed RT and NRT service are modeled as QG&MPF and M2PF. Since M2PF usually allocate the resource for RT service in higher priority, and the throughput improvement provided by multiuser diversity gain of NRT users are sacrificed to guarantee the data rate of RT services. So QG&MPF achieves much better performance than M2PF. For 2×4 MIMO case, QG&MPF can support 40 RT user and 40 NRT users in 10MHz bandwidth simultaneously, and the system throughput of QG&MPF can approach 32Mbps; while M2PF can only support 15 RT users and 15 NRT users, and the system throughput is about 11.5Mbps.

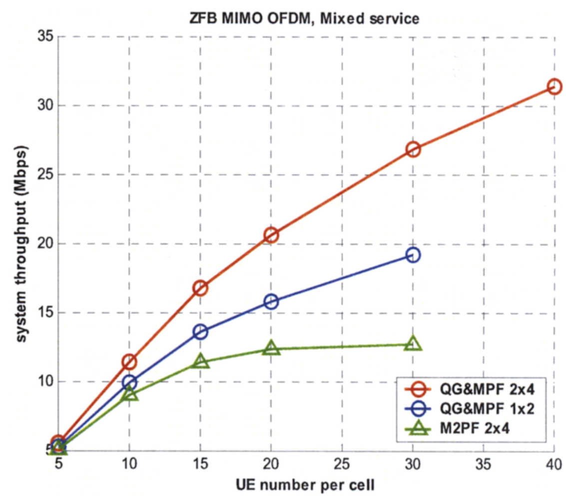

Figure 5. Mixed services: system throughput vs. user number

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