Sohn *et al. EURASIP Journal on Wireless Communications and Networking* 2013, **2013**:52
http://jwcn.eurasipjournals.com/content/2013/1/52

EURASIP Journal on
Wireless Communications and Networking
a SpringerOpen Journal

RESEARCH **Open Access**

A novel multicast scheme for feedback-based multicast services over wireless networks

Kyungho Sohn[1*], Han-Seok Kim[2] and Young Yong Kim[1]

Abstract

Recently, a point-to-multipoint transmission is a promising technology in the limitation of wireless resources and surging of subscribers, and an optimal to deliver real-time streaming service such as video/audio conference, digital live cast, and so on. There are two types of point-to-multipoint transmission; broadcast and multicast. Broadcast services deliver the information to all receivers in a cell and multicast services deliver the information to a multicasting group. Traditional approaches to multicast services operate by radiating transmission power with the lowest modulation level and coding rate which may be much lower than the lowest acceptable rate for all the multicast subscribers of a multicasting group. While such an approach has the advantage of simple implementation, this method may incur substantial performance penalties such as low spectral efficiency and a large amount of power consumption. To solve this issue, wireless multicasting with channel state information has been investigated in many research studies. However, the overhead of feedback information is a heavy drawback to the achievement of good network performance. In feedback-based multicast services, the system performance is also mostly dependent on the receivers with the lowest channel quality in a multicasting group. Hence, receivers who have better channel condition can receive multicast data successfully without channel quality indicator (CQI) feedback. In this point of view, the feedback-based multicast scheme should aim to achieve high resource efficiency by reducing unnecessary CQI feedback and transmission optimization by dynamically adapting modulation and coding selection (MCS) level according to the variations of the channel state. We show that the proposed scheme enhances the system throughput by dynamically adapting the MCS level according to variations of the CQI and also reduce CQI feedback by transiting from a feedback state to a non-feedback state according to a channel gain and recent frame error rate of each receiver. Finally, the proposed scheme does not need any additional control signaling overhead and also can be expanded and employed in any kind of systems, such as WCDMA, WiMAX, LTE, and LTE-Advanced.

Keywords: multicast services, channel state information, channel quality indicator, feedback reduction

1 Introduction

1.1 Point-to-multipoint transmission in wireless networks

Recently, wireless markets are surging around the world because of smartphone. A smartphone is a mobile phone offering advanced capabilities, often with PC-like functionality (PC-mobile handset convergence). We can call somebody, read an e-book, listen to the music, and watch TV by using this little handset. Since demand for advanced mobile devices has growing for several years, more and more subscribers try to use a wireless communication. Under these circumstances, one of the most challenging issues for future wireless communications is to support a large number of subscribers and to ensure the guarantee of quality-of-service (QoS) requirements under the limited availability of frequency spectrum.

In order to satisfy these issues, up to now, the main wireless applications have been unicast multiuser systems. "Unicast" means that the information is headed to only one receiver. It implies that information is transmitted by point-to-point communication method. However, with increasing wireless data coverage and capabilities of handheld devices, multimedia streaming-based applications such as video and audio conferences, digital broadcasting services, and local advertisement are making critical system demands. For these types of applications, point-to-multipoint services (i.e., the same information is headed

*Correspondence: heroson7@yonsei.ac.kr
[1]School of Electrical and Electronic Engineering, Yonsei University, 134 Shinchon-dong, Seodaemoon-gu, Seoul, Korea
Full list of author information is available at the end of the article

to multiple selected receivers in a certain group) offer a significant improvement compared with unicast services, since they allow the simultaneous transmission of packets to multiple destinations which enables to use radio resource more efficiently [1,2].

Multimedia broadcasting and multicasting services (MBMS) [3], broadcast-multicast services, and multimedia broadcast service [4] have already been studied and treated as an important development in the 3GPP, 3GPP2, and IEEE 802.16 standards, respectively. In addition, multicasting systems such as digital video broadcasting-handhelds and media forward link only [5] systems were launched as part of the streaming services.

1.2 The feedback issues for multicast services in wireless networks

1.2.1 The feedback implosion problem

Reliable multicast services like these applications are an efficient method to deliver the same message reliably throughout the wireless network. However, how to maintain reliable multicast services over the error-prone wireless environment is a great challenge, since time varying channel will cause unexpected packet error. Automatic Repeat reQuest (ARQ) is popular error recovery mechanisms. To guarantee reliable data delivery, ARQ, also known as automatic repeat query, uses positive acknowledgements (messages sent by the receiver indicating that it has correctly received a data packet) or a negative acknowledgement (NACK) for the lost data packet, and timeouts (specified periods of time allowed to elapse before an acknowledgment is to be received) over an wireless networks. If the transmitter does not receive an acknowledgment before the timeout, it usually re-transmits the packet until the transmitter receives an acknowledgment or exceeds a predefined number of re-transmissions. However, when a lot of receivers are located in a cell, ARQ can cause a large number of ARQ feedback messages to be sent to the transmitter simultaneously, which is referred to as the feedback implosion problem. It may overwhelm the sender processing capability, overflow the buffers, and cause network congestion near the transmitter. This feedback implosion problem is exacerbated as the number of receivers is increasing. Especially, it is not practical for multicast services under the limitation of uplink channel resource and power consumption of receiver. To solve this problem, many literatures are published [6-8]. However, these literatures all consider the feedback implosion problem, that is, the authors focus on only ACK/NACK feedback problem. This feedback implosion problem is contradistinguished from the problem which is considered in this article. In this article, we do not consider ACK/NACK feedback but only focus on for channel quality indicator (CQI) feedback problem.

1.2.2 Feedback-based multicast services

Since subscribers in a multicasting group listen to a common channel and they share same time and frequency resources, as well as same modulation and coding selection (MCS), these traditional approaches to multicast services operate by radiating transmission power with the lowest modulation level and coding rate which may be much lower than the lowest acceptable rate for all the multicast subscribers of a multicasting group [2,5]. It implies that a transmitter does not need to know about CSI of each receiver, thus, in Section 1.2.1, the authors only consider the feedback implosion problem. In general, these multicast services are not feedback-based system. Therefore, these methods cannot provide efficient performance due to the nature of the time varying channels. This implies that in order to fulfill QoS requirements MCS has to be adjusted to the weakest terminal of a multicasting group. So, the system performance of traditional scheme is largely limited by the subscriber with the worst channel condition [9]. While such an approach has the advantage of simple implementation, this method may incur substantial performance penalties such as low spectral efficiency and a large amount of power consumption.

To solve this issue, wireless multicasting with CSI has been investigated in many research studies [1,2,4]. Unlike the usual "blind" isotropic multicasting scenario, the availability of CSI allows the transmitter to select the optimized transmission. To use the CSI for multicast services enables a transmitter to exploit MCS schemes according to the wireless channel variations under the constraints of block error rate (BLER) or Frame Error Rate (FER) for each individual intended receiver. It can be accomplished in more general scenarios through the use of pilot signals which are periodically transmitted from the transmitter. The receivers can then feed back their CSI through a feedback channel. Figure 1 shows the procedure of this scenario.

However, in this scenario, the overhead of feedback information is a heavy drawback to the achievement of good network performance. In addition, there is no feedback scheme designed for multicast services, in order to acquire receiver's CSI, some periodic feedback method like unicast services should be deployed, but suffering from overhead and scalability problem [4]. Therefore, in order to handle CSI feedback overhead, a novel multicast scheme for feedback-based multicast services is needed.

1.3 Related work

In feedback-based multicast services, the system performance is also mostly dependent on the receivers with the lowest channel quality in a multicasting group. Hence, the proposed scheme adaptively feeds back available CSI according to a channel gain and recent FER of each receiver. Thus, one can reduce CSI feedback overhead

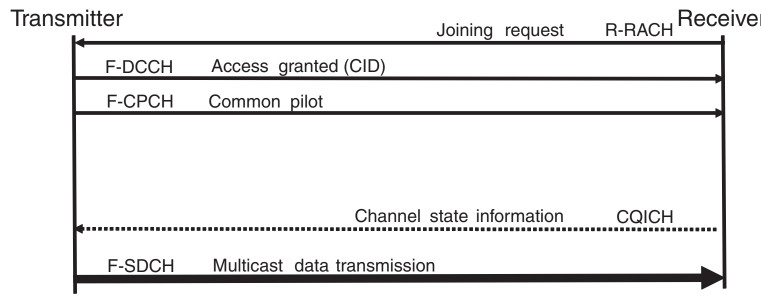

Figure 1 Signal flow of feedback-based multicast services.

while satisfying QoS requirements and achieve transmission rate adaptation by altering the modulation and coding scheme on the frame. Moreover, the proposed scheme needs no additional physical control channel and the algorithm is triggered by the receiver. Therefore, there is no additional message to control from the transmitter. Because of all these reasons, the proposed scheme is easy to implement. A receiver measures the received channel quality, such as signal-to-interference ratio (SINR), and converts it to discrete CQI steps. Then, in the proposed scheme, this receiver makes a decision whether it reports the CQI or not according to an SINR and recent FER. CQI is generally used in choosing the correct MCS at the transmitter. This link adaptation (LA) makes the multicast transmission efficient. Performance of the proposed scheme is evaluated in terms of both feedback overhead and system goodput as guaranteeing the target FER. The proposed scheme aims to achieve high resource efficiency by reducing unnecessary CQI feedback and transmission optimization by dynamically adapting MCS level according to the variations of the CQI.

Related work [10] considers the overhead for feedback signal in 3GPP LTE MBMS. Cai et al. [10] analyzed path loss-based, geometry-based, and BLER-based algorithms, and conclude that using geometry for selecting feedback user equipment (UE) is the optimal solution and four feedback UEs are enough to meet the coverage requirement. However, the authors assume that UEs never move or leave the system until the end of the simulation run (5 s) and no fast fading is considered for path loss-based and geometry-based algorithms. This implies that channel conditions of UEs are barely changed or even still constant until the end of simulation time. In this ideal situation, geometry-based algorithm might be optimal. In practical situation (i.e., when the wireless channel varies frequently and UEs are moving), it is obvious that the performance of geometry-based algorithm is decreasing.

The remainder of the article is organized as follows. Section 2 presents the proposed scheme. In this section, state transition diagrams, protocol description, and framework for the proposed scheme are introduced. Performance evaluation is shown in Section 3. First, the proposed scheme is formulated by discrete Markov process in Section 3.1. Implementation models are presented in Section 3.2. We assume that the proposed scheme will be introduced in 3GPP LTE MBMS [11] in order to compare with conventional scheme (geometry-based and BLER-based algorithms) [10]. Simulation results are presented in Section 3.3. We compare the proposed scheme with non-feedback scheme, full feedback scheme, geometry-based algorithm, and BLER-based algorithm in terms of system goodput, CQI feedback overhead, and long-term QoS (FER). Finally, Section 4 concludes this article.

2 Proposed multicast scheme

In order to better explain the proposed scheme and compare with related work, we will assume that the proposed scheme will be used in 3GPP LTE TDD systems with UL/DL ratio 1:1. In the following, we assume that the transmitter is an evolved Node B (eNB) and the receivers are UEs [11]. In this section, it is also assumed that the MBMS service occupies the whole bandwidth so that there is no need for packet scheduling, even though only one resource block is used for multicast services. In the proposed scheme, an UE transits to a certain state according to an own QoS parameter, such as FER. In each state, UEs decide to send CQI feedback or flag state indicator or joining request message. If an UE satisfies QoS requirement, it will not send CQI feedback. This mechanism can be used to reduce feedback overhead.

2.1 Signal flow of feedback-based multicast services

As mentioned above, signal flow of feedback-based multicast services is illustrated in Figure 1 which shows a general scenario of feedback-based multicast services [4,10].

Figure 2 shows the initial procedure from steps 1 to 3 and the proposed feedback reduction scheme starts to operate at step 4.

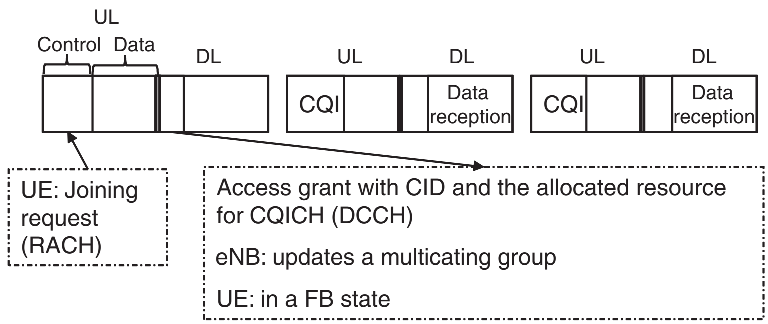

Figure 2 Initial procedure of the proposed scheme.

1. An UE who wants to join in a multicasting group sends a joining request message through a reverse link random access channel (R-RACH).
2. An eNB authenticates this UE and notifies by means of an access granted message using common identification (CID) and allocating the resource for channel quality indicator channel (CQICH) through a forward link dedicated control channel (F-DCCH). The receiver is now included in the multicasting group.
3. Having received the access granted message, the UE tries to catch the common pilot signal which comes from the eNB though a forward link common pilot channel (F-CPCH).
4. The UE then calculates the CQI level, and using the proposed scheme it feeds back any available CQI value according to an instantaneous SINR.
5. The eNB radiates the multicasting data to multiple receivers through a forward link shared data channel by using acquired CQIs.

2.2 State transition diagram, protocol description, and framework design

Figure 3 shows the state transition diagram for the proposed scheme. There are three states and the transition of state depends on the SINR of each receiver. The UEs with poor SNIR are very likely to stay in a feedback state (FB state). On the other hand, the UEs who have good SINR are more likely to be in a non-feedback state (NFB state). A flag state is a preparatory stage before an NFB state.

Initially, when the UE enters into multicast services, the UE feeds back its CQI through a CQICH until it receives multicast data without error for N sequential times. N is decided according to the QoS constraint, FER. This is called an FB state. Since the eNB knows all the CQIs of the UEs which are in an FB state, the eNB uses LA to determine MCS efficiently. Therefore, transmission optimization can be achieved through a down link.

After receiving the multicasting data during N frames, the UE transits to a flag state. It feeds back the flag state indicator, which is a just one bit, through a CQICH. Since the UE has already satisfied the FER constraint, the eNB recalls the CQICH which was allocated to the UE on a flag state. Since this recalled CQICH is able to be used by other UEs, CQICH management can obtain more benefit when the number of CQICHs is smaller than that of the UEs.

Moreover, the eNB holds the session information for this UE and allocates a new dedicate control channel (DCCH) for fast joining requests. When the frame error occurs, the UE can use this DCCH instead of R-RACH to avoid the need for reauthentication.

Then, the UE transits to an NFB state; in this state the UE no longer feeds back its CQI since the UE does not have a CQICH allocated by the eNB. This mechanism reduces unnecessary CQI feedback. The eNB radiates the multicasting data by determining MCS level according to the worst CQI level of all CQIs. Consequently, UEs with better SINR can decode the multicasting data without CQI feedback. This is the key idea of the proposed scheme. Therefore, high resource efficiency and low interference can be achieved through an uplink. In addition, the UE can save transmission power, which is a very sensitive issue with hand-held devices.

If the multicasting data reception continuously succeeds during on an NFB state, this will imply that the target FER is satisfied sufficiently and there still is room to maintain the quality of multicasting data. In this case, even though the frame error occurs (i.e., it implies that this UE has the worst SINR in the multicasting group.), the receiver does not need to transit to an FB state but just remains in an NFB state as long as it satisfies the target FER. If the UE on an NFB state receives the multicasting data continually N times when in an NFB state, the UE will be endowed with credit and if a frame error occurs, this credit will be able to be discarded. We refer to this algorithm as a non-feedback counter. Since the history of each UE's SINR is reflected in a credit, it reduces more CQI feedback. This implies that it avoids the frequent transition to an FB state by the temporary falling of the channel gain.

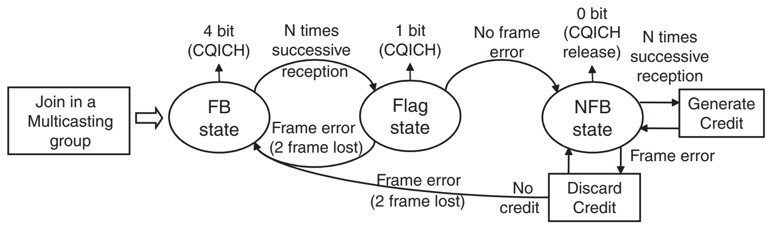

Figure 3 State transition diagram of the proposed scheme.

If a frame error occurs and there is no remaining credit, the UE will transit to an FB state. In order to satisfy the target FER, the UE transits to an FB state at once and requests a new CQICH. In this case, the UE sends a "fast joining request" message through a DCCH instead of R-RACH. Since the eNB holds the session information for this receiver, the authentication process is not necessary. The eNB sends the "access granted" message using CID and the allocated resource for CQICH through an F-DCCH. This procedure takes time of two frames, thus the UE lost two frames when a frame error occurs. Then the UE feeds back its CQI through a new CQICH.

The framework for the proposed scheme is presented at Figure 4. In the proposed scheme, if every UE is in an NFB state, the eNB will use the CQI value of the previous frame.

3 Performance evaluation

In this section, we analyze the proposed algorithm by numerical and simulation methods.

3.1 Numerical model

We formulate the proposed algorithm by discrete Markov process. A discrete Markov process is a discrete random process with the property that the next state depends only on the current state. A discrete random process means a system which is in a certain state at each "step", with the state changing randomly between steps. The Markov property states that the conditional probability distribution for the system at the next step (and in fact at all future steps) given its current state depends only on the current state of the system, and not additionally on the state of the system at previous steps:

$$P(X_{n+1}|\, X_1, X_2, \ldots, X_n) = P(X_{n+1}|\, X_n)$$

Since the system changes randomly, it is generally impossible to predict the exact state of the system in the future. However, the statistical properties of the system's future can be predicted. The changes of state of the system are called transitions, and the probabilities associated with various state-changes are called transition probabilities. The set of all states and transition probabilities completely characterizes a Markov process. If the Markov process is a time-homogeneous Markov process, so that the process is described by a single, time-independent matrix p_{ij} then the vector Π is called a stationary distribution if its entries Π_j sum to 1 and it satisfies

$$\Pi_j = \sum_{i \in E} \Pi_i p_{ij} \quad \text{(for each } j \ \in E) \tag{1}$$

where p_{ij} is the probability of going from state i to state j in single time steps:

$$p_{ij} = \Pr(X_1 = j \big|\, X_0 = i)$$

Equation 1 is referred as "Global Balance Equation".

The proposed scheme is formulated by discrete Markov process in Figure 5.

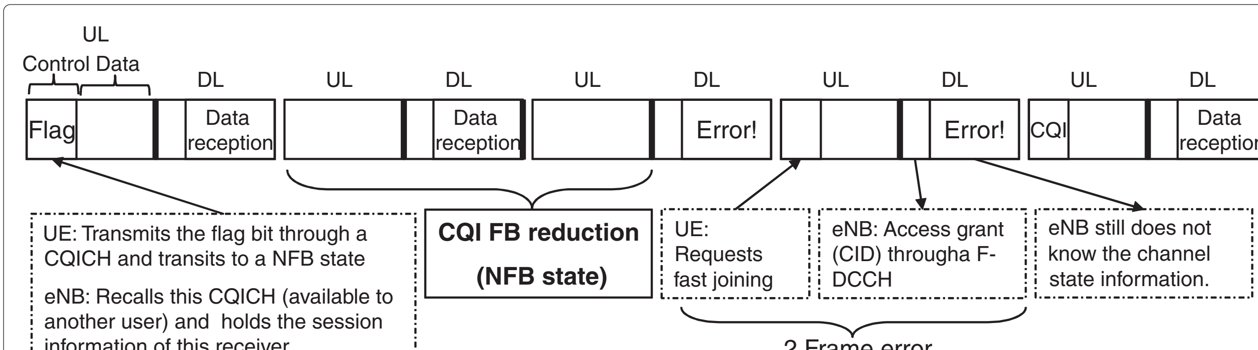

Figure 4 Framework for the proposed scheme.

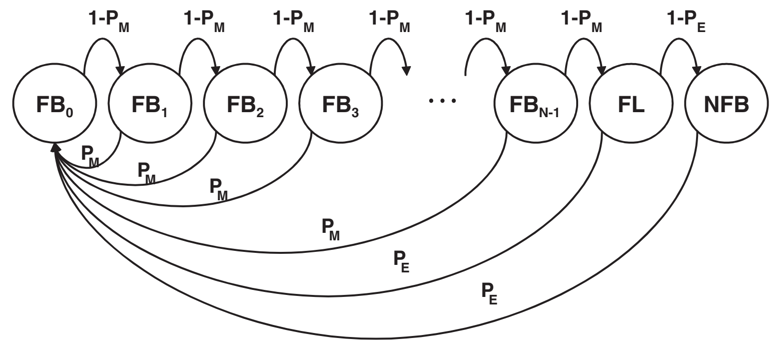

Figure 5 **Discrete Markov process of the proposed scheme.**

In our formulation, the state space is finite and each state is recurrent non-null. This implies that first return time to state i (the "hitting time") is finite, moreover, the steady-state probability Π_i is finite and unique. "FB" means feedback state, and when multicast data are received successfully, states are transit to "FB$_k$" state with probability of $(1 - P_M)$. UE also feeds back its CQI through a CQICH in this state. N depends on target QoS constraint of system, therefore this value is fixed when multicast service is provided. "FL" and "NFB" are flag and non-feedback states, respectively. When a frame error occurs, even though the UE lies in any state, it transits to "FB" state immediately with probability of P_E which means the probability of frame error.

In Figure 6, global balance equation in FB$_0$ state is

$$\Pi_{\mathrm{FB}_0} \times (1 - P_M) = \Pi_{\mathrm{FB}_1} \times P_M + \Pi_{\mathrm{FB}_2} \times P_M + \cdots + \Pi_{\mathrm{FB}_{N-1}} \times P_M + \Pi_{\mathrm{FL}} \times P_E + \Pi_{\mathrm{NFB}} \times P_E$$

$$\Pi_{\mathrm{FB}_0} \times (1 - P_M) = \sum_{k=1}^{N-1} \Pi_{\mathrm{FB}_k} \times P_M + (\Pi_{\mathrm{FL}} + \Pi_{\mathrm{NFB}}) \times P_E$$

where P_M is the probability of CQI mismatch which means CQI feedback is crashed for some reasons even though the UE feeds back its CQI through a CQICH successfully. In this case, the UE receives an incorrect multicasting date at very next downlink frame since the multicast date is modulated to an incorrect MCS level by the eNB. This CQI mismatch problem is out of focus in this thesis, so we do not solve it. However, we consider this CQI mismatch and analyze it by numerical and simulation methods.

Global balance equation of FB$_1$ state is

$$\Pi_{\mathrm{FB}_1} \times (1 - P_M) + \Pi_{\mathrm{FB}_1} \times P_M = \Pi_{\mathrm{FB}_0} \times (1 - P_M)$$

$$\Pi_{\mathrm{FB}_1} = \Pi_{\mathrm{FB}_0} \times (1 - P_M) \tag{2}$$

And global balance equation of FB$_2$ state is

$$\Pi_{\mathrm{FB}_2} \times (1 - P_M) + \Pi_{\mathrm{FB}_2} \times P_M = \Pi_{\mathrm{FB}_1} \times (1 - P_M) = \Pi_{\mathrm{FB}_0} \times (1 - P_M)^2$$

$$\Pi_{\mathrm{FB}_2} = \Pi_{\mathrm{FB}_0} \times (1 - P_M)^2 \tag{3}$$

Global balance equation of FB$_3$ state can be achieved as

$$\Pi_{\mathrm{FB}_3} \times (1 - P_M) + \Pi_{\mathrm{FB}_3} \times P_M = \Pi_{\mathrm{FB}_2} \times (1 - P_M) = \Pi_{\mathrm{FB}_0} \times (1 - P_M)^3$$

$$\Pi_{\mathrm{FB}_3} = \Pi_{\mathrm{FB}_0} \times (1 - P_M)^3 \tag{4}$$

Therefore, from Equations 2, 3, and 4, global balance equation of state FB$_k$$(k = 1, 2, 3, \ldots, N-1)$ is described as follow

$$\Pi_{\mathrm{FB}_k} = \Pi_{\mathrm{FB}_0} \times (1 - P_M)^k \quad (\text{for} \quad k = 1, 2, 3, \ldots, N-1) \tag{5}$$

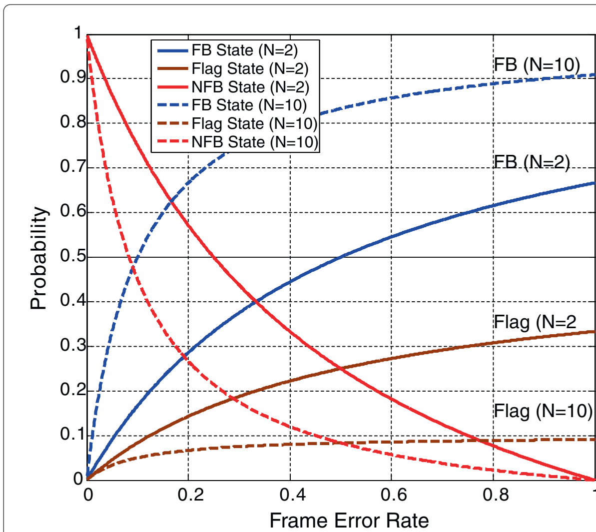

Figure 6 **Steady-state probability without CQI mismatch.**

Global balance equation of flag state is

$$\Pi_{\mathrm{FL}} = \Pi_{\mathrm{FB}_0} \times (1 - P_M)^N \tag{6}$$

Global balance equation of NFB state is able to be achieved.

$$\Pi_{\mathrm{NFB}} \times P_E = \Pi_{\mathrm{FL}} \times (1 - P_E)$$

So,

$$\Pi_{\mathrm{NFB}} = \Pi_{\mathrm{FL}} \times \frac{(1 - P_E)}{P_E} = \Pi_{\mathrm{FB}_0} \times \frac{(1 - P_M)^N (1 - P_E)}{P_E} \tag{7}$$

Now, sum of each state has to 1, therefore normalized equation satisfies

$$\Pi_{\mathrm{FB}_0} + \Pi_{\mathrm{FB}_1} + \Pi_{\mathrm{FB}_2} + \cdots + \Pi_{\mathrm{FB}_{N-1}} + \Pi_{\mathrm{FL}} + \Pi_{\mathrm{NFB}} = 1$$

$$\Pi_{\mathrm{FB}_0} + \sum_{k=1}^{N-1} \Pi_{\mathrm{FB}_k} + \Pi_{\mathrm{FL}} + \Pi_{\mathrm{NFB}} = 1 \tag{8}$$

Equation 8 is substituted for Equations 5, 6, and 7.

$$\Pi_{\mathrm{FB}_0} + \sum_{k=1}^{N-1} \Pi_{\mathrm{FB}_0} \times (1 - P_M)^k + \Pi_{\mathrm{FB}_0} \times (1 - P_M)^N + \Pi_{\mathrm{FB}_0} \times \frac{(1-P_M)^N (1-P_E)}{P_E} = 1$$

$$\Pi_{\mathrm{FB}_0} \times \left\{ 1 + \sum_{k=1}^{N-1} (1 - P_M)^k + (1 - P_M)^N + \frac{(1-P_M)^N (1-P_E)}{P_E} \right\} = 1$$

Now, we can achieve the steady-state probability of FB state:

$$\Pi_{\mathrm{FB}_0} = \frac{1}{\left\{ 1 + \sum_{k=1}^{N-1} (1 - P_M)^k + (1 - P_M)^N + \frac{(1-P_M)^N (1-P_E)}{P_E} \right\}} \tag{9}$$

Using Equations 5, 6, 7, 9 we can derive steady-state probability of all states.

As mentioned above, N is a fixed value and CQI mismatch is out of focus in this thesis, therefore we can assume P_M to some reasonable values.

The steady-state probability of FB state, flag state, and NFB state are depicted in Figure 6 when N is 2 and 10, respectively. We do not consider CQI mismatch in this case. The steady-state probability of FB state and flag state is increasing according to the FER. When a frame error occurs frequently, the UE has to stay in an FB state. In this figure, a dotted line is the steady-state probability when N is 10. The UE can transit to an NFB state after N multicasting dates are received successfully. Therefore, the steady-state probability of FB state is increasing according to N, target QoS requirements.

Figure 7 shows the steady-state probability of FB state (a solid line) and NFB state (a dotted line) when N is 10 and CQI mismatch is occurs. When CQI mismatch occurs, even though UE stays in FB state, frame error occurs. Therefore, UE has to stay in FB state longer than the case of no CQI mismatch.

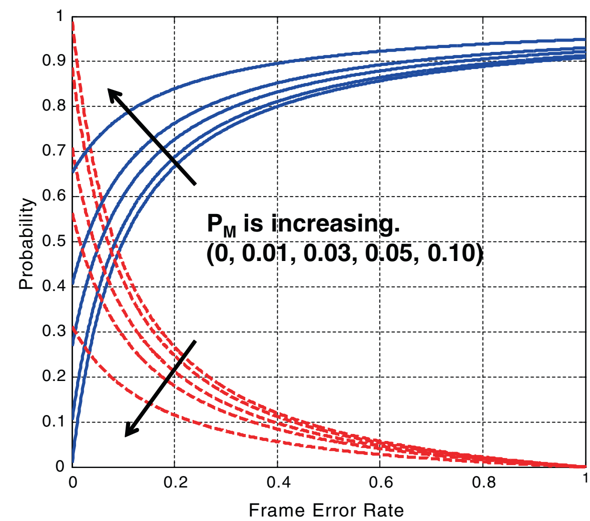

Figure 7 Steady-State probability with CQI mismatch($N = 10$).

Now we analyze how many CQI information are reduced. Average feedback bits can be written as

$$4 \times \left(\Pi_{\mathrm{FB}_0} + \sum_{k=1}^{N-1} \Pi_{\mathrm{FB}_k} \right) + 1 \times \Pi_{\mathrm{FL}} \tag{10}$$

where 4 is required bits for wideband CQI feedback [11] and 1 is required bit for flag indicator. Figure 8 shows amount of average CQI feedback versus FER using Equation 10 when N is 38 and no CQI mismatch occurs. Note that the probability of staying in FB states is the total sum of Π_{FB_0}, $\sum_{k=1}^{N-1} \Pi_{\mathrm{FB}_k}$, and Π_{FL}. When UE sends their CQI feedback with full feedback scheme, CQI feedback rate takes 4 kbps. "FB ratio" means the amount of average CQI feedback in the proposed scheme over 4 kbps in full feedback scheme. In this figure, we expect that CQI feedback reduction will be achieved by using the proposed scheme. N is the number of successive receptions and we consider this as 38, which means the target FER constraint is 5% in the worst case. Since two frames will be lost when a frame error occurs, 38 frames are always received successfully. Therefore, at least 95% (=38/40) of all frames are definitely received. In the proposed scheme, about 70% CQI feedback is needed compared with the full feedback scheme, when target FER constraint is 5% in the worst case.

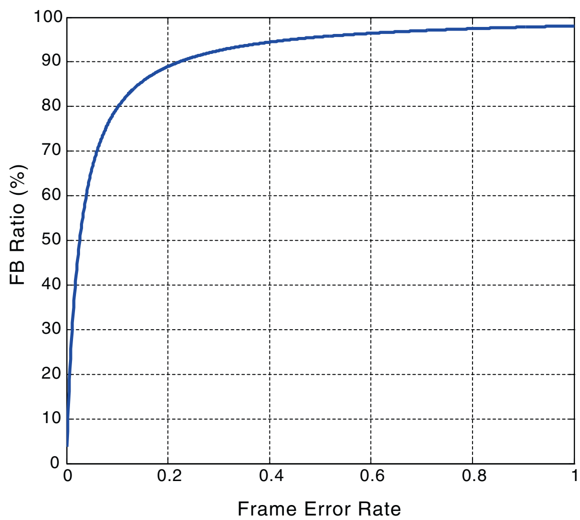

Figure 8 Feedback ratio versus FER.

3.2 Implementation models

We assume that the proposed scheme will be introduced in 3GPP LTE MBMS [11] in order to compare with geometry-based algorithm and BLER-based algorithm [10] and the main content of the multicast service is video streaming. In order to evaluate the performance of the proposed schemes, we apply the Rudimentary Network Emulator (RUNE) [12]. RUNE is a set of MATLAB functions that handle various aspects of cellular networks, that is, mobiles, base stations, propagation loss, interference, and mobility. Therefore, that makes it possible to simulate a wireless networks in reality. With simulation we aim at more realistic comparison with other schemes since the geometry-based and BLER-based algorithms are implemented in ideal situation.

The performance evaluation is based on multi-cell system model. The transmission channel model includes path loss, shadow, and multipath fading model which follows the parameters of Table 1. Distance attenuation is considered for path loss and the shadow fading is modeled using the lognormal distribution and the correlation distance. For multipath fading modeling, typical urban (TU) is used. In addition, we apply the proposed scheme to a transmission mode 1 (i.e., single-antenna port) among seven transmission modes of the 3GPP LTE multiple antenna implementation.

The initial location of each UE is randomly distributed in the center cell. Only UEs in center cell are simulated, other eNBs simply act as static interference source since eNB transmits the multicasting data via downlink. UEs move around in the cell but never leave the system until the end of simulation. The mobility fact only has an influence on channel variation so that there is no procedure for hand-off.

Table 1 Link level and system level simulation environment

Parameter	Value
UE distribution	Uniform
Data generation	Full queue
Number of UE	30 users
UE mobility	3 km/h, 50 km/h
Cellular layout	Hexagonal grid
Multi-cell model	2-tier (19 cells)
Cell radius	500 m
System bandwidth	1.4 MHz
Number of resource blocks	1
Transmission Power of eNB	12 W
interference calculation [10]	Only users in center cell are simulated,
	other eNBs simply act as static interference sources.
Antenna [11]	Single antenna (transmission mode 1)
Path loss attenuation coefficient	3.5
Shadow fading model	Log-normal distribution
Standard deviation	8.0 dB
Inter-site correlation	0.5
De-correlation distance	50 m
Fast fading model	TU 20 Taps
Thermal noise	−174 dBm
Parameter	Value
Frame length	1 ms
Simulation time	5 s/run, 200 runs
Required bit for CQI feedback [11]	4 bits
Required bit for flag state indicator	1 bit
Required bit for joining message	2 bit
Target FER constraint	5%
The number of successive reception (*N*)	38

The CQI signaling delay is not taken into account as it is expected to affect performance of all the evaluated schemes.

In the simulation it is assumed that the number of successive receptions, N, is 38, which means the target FER constraint is 5% in the worst case. Since two frames will be lost when a frame error occurs, 38 frames are always received successfully. Therefore, at least 95% (=38/40) of all frames are definitely received.

Depending on channel conditions, different coding schemes and modulations can be used for each UE. Possible modulations are QPSK (Quadrature Phase Shift Keying), 16QAM (Quadrature Amplitude Modulation), 64QAM in LTE [11]. LTE defines different MCS suitable for 15 different steps of the CQI which feedback by the UE. The CQI indices and their interpretations are given in Table 2. Transport block size [11] and target SINR [13] according to modulation order are also given. All of the 15 MCS defined by the CQI values in the LTE standards have been used [11]. Simulations were performed for the MCSs corresponding to each CQI value in LTE.

In conventional full feedback scheme, all UEs feed back there CQI at every frame, thus it is obvious that the amount of feedback overhead is directly proportionate to the increased number of UEs.

In geometry-based algorithm, users are differentiated by the geometry factor which is the ratio of total base station power and interference from the other cells including thermal noise. As we assume fully queued network, the value of geometry factor equals the calculated SINR for each UE in the reuse factor one case. Therefore, the geometry factor can be provided by UE-side measurement of the downlink common pilot channel [14].

In BLER-based algorithm, users are differentiated by the geometry factor first, and then users are sorted by BLER. Only three users feed back their CQI index to minimize each BLER.

Table 1 lists the simulation assumptions and parameters. By using these simulation parameters, we compare the proposed scheme with the full feedback scheme and geometry-based algorithm in terms of amount of CQI feedback and system throughput. In all the simulation examples, the eNB sends the same multicasting data; thus, the image quality depends on the FER of each UE.

Table 2 CQI and MCS mapping table for target SINR

CQI index	Modulation	Transport block size [11]	Target SINR (dB) [13]
1	QPSK	152	−15.4232
2	QPSK	208	−14.615
3	QPSK	256	−13.538
4	QPSK	328	−12.462
5	QPSK	408	−11.385
6	QPSK	504	−10.308
7	16QAM	936	−9.2308
8	16QAM	1032	−8.1538
9	16QAM	1192	−7.2115
10	64QAM	1800	−6.0000
11	64QAM	1928	−4.9231
12	64QAM	2152	−3.5769
13	64QAM	2344	−2.0962
14	64QAM	2600	−0.6154
15	64QAM	2792	1.8077

3.3 Simulation results

This section presents the simulation results in terms of CQI feedback overhead, system goodput, long-term QoS (FER), and short-term QoS (burst error). All simulation results are the mean values of 200 runs.

3.3.1 Results of CQI feedback overhead

Figure 9 shows the amount of CQI feedback for each user compared with the full feedback scheme when UE moves at 0 km/h. In Section 3.1, we formulate the proposed scheme by discrete Markov process. Note that we do not analyze NFB counter and request for new CQICH in Figure 5.

In Figure 9, star-markers represent CQI feedback ratio when an NFB counter is not used. There is a slice gap between numerical results and simulation results when FER is more then 3%. Since in numerical model the UE transits directly to an FB state when a frame error occurs. However, in implementation model when a frame error occurs, the UE has to request new CQICH, and then transits to an FB state. This implies that two frames are lost when a frame error occurs in implementation model and additional feedback bits are needed for request of new CQICH compared with the numerical model.

Also round-marker represent CQI feedback ratio when an NFB counter is used. The users who have low FER are able to get more credits; therefore, it will stay still in an NFB state until credit is vanished. Due to this reason, there are a huge gap between numerical model and implementation model when NFB counter is used. Note that feedback ratio of the users who have high FER is almost same at no NFB counter case since they do not get credits. The number of credit is described in Figure 10. The UEs with good channel gain are very likely to stay in

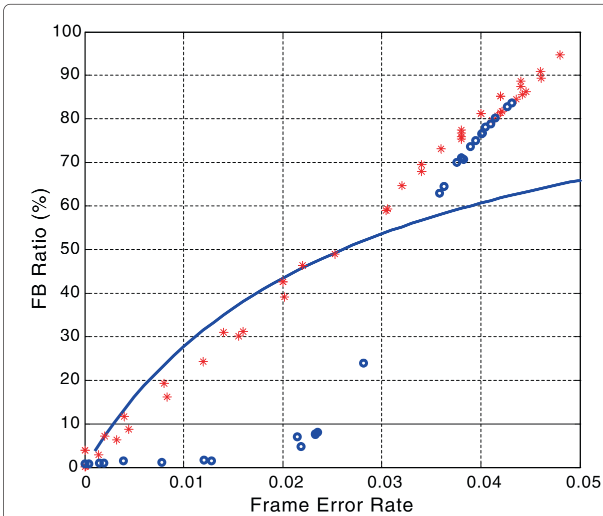

Figure 9 Feedback ratio versus FER with numerical model.

an NFB state; therefore, the amount of CQI feedback is extremely low compared with the full feedback scheme. On the other hand, the users who have poor channel gain are more likely to be in an FB state. Even though these users feed back their CQI, the CQI feedback of the proposed schemes is much lower than that of the full feedback scheme. Due to the nature of the time varying channels, these users may have better channel gain than others and can remain in an NFB state. This mechanism reduces unnecessary CQI feedback. Consequently, the proposed scheme extremely reduces the amount of CQI feedback compared with full feedback scheme.

3.3.2 Results of system goodput

Figures 11 and 12 compare the proposed scheme with full feedback scheme, geometry-based algorithm, and BLER-based algorithm in terms of the system goodput when not counting the transport blocks received in error.

Non-feedback scheme has worst performance since this scheme does not use CQI feedback, therefore eNB cannot use AMC technique. Meanwhile, the proposed scheme has better throughput than the non-feedback scheme, but this suffers from FER at most 5%. In the proposed scheme, some users who have a low SINR can be dropped (i.e., cannot receives a multicasting data in a certain frame) as far as the FER of UE permits until 5% FER. This mechanism allows an eNB to adopt the higher modulation than conventional feedback scheme in a certain frame. The goodput of geometry-based algorithm is the worst since in this scheme UEs send their CQI at a slow rate (0.2 Hz). This implies that the eNB might lose a chance to adapt the higher modulation order when the channel condition of all UEs is better than pervious frame. Nevertheless BLER-based algorithm only focus on the FER, goodput is better than geometry-based algorithm since the UE feeds back its CQI more frequently.

In our simulation, antenna gain, cell sectorization, hybrid automatic repeat request, and multi-antenna transmission scheme are not considered. Therefore, SINR is not enough high to adopt high-order modulation such as 16QAM or 64QAM. If these schemes are established all, it is obvious that the system goodput gap between the proposed scheme and the conventional scheme will be increasing since the higher-order modulation can be adopted more frequently in the proposed scheme.

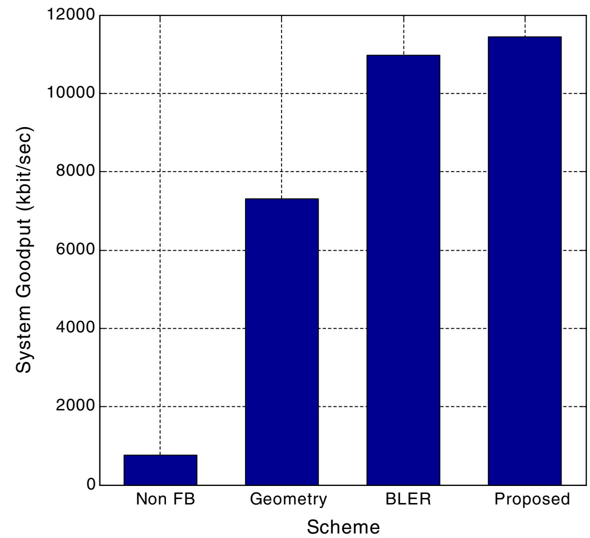

Figure 11 **System goodput comparison when UE moves at 3 km/h.**

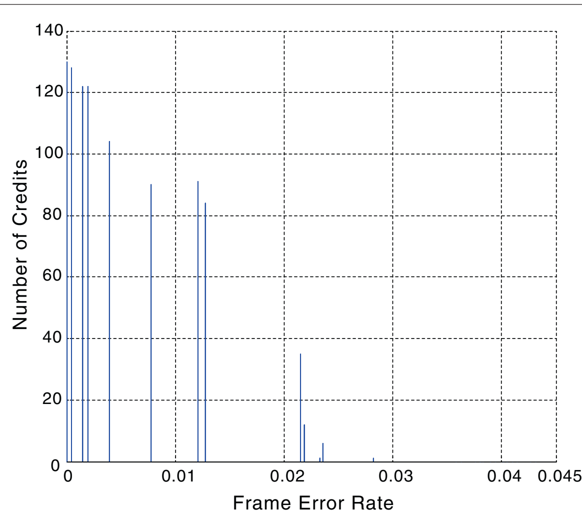

Figure 10 **Number of credit versus FER.**

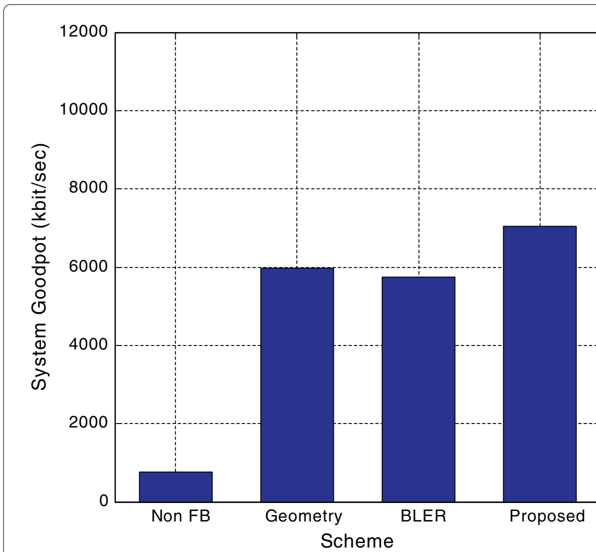

Figure 12 **System goodput comparison when UE moves at 50 km/h.**

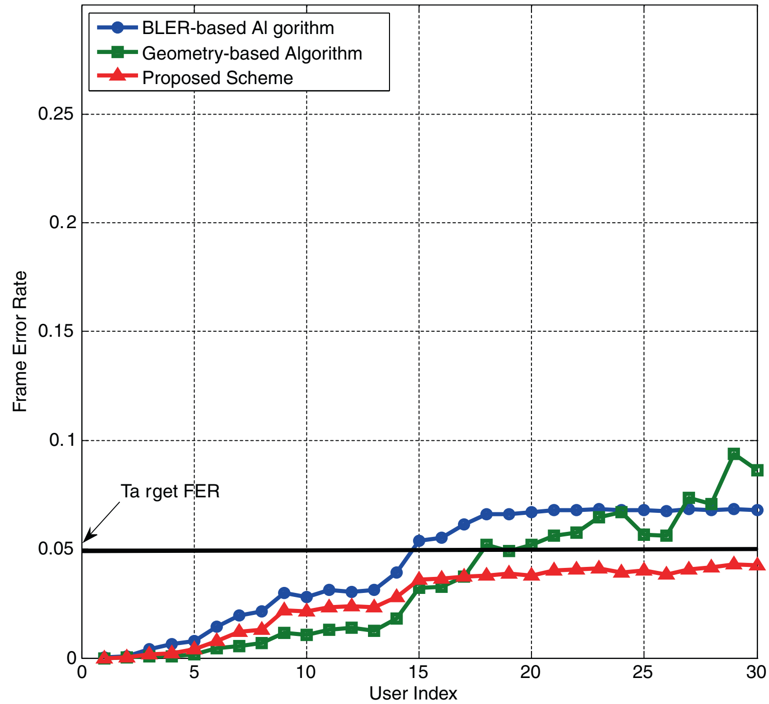

Figure 13 FER comparison when UE moves at 3 km/h.

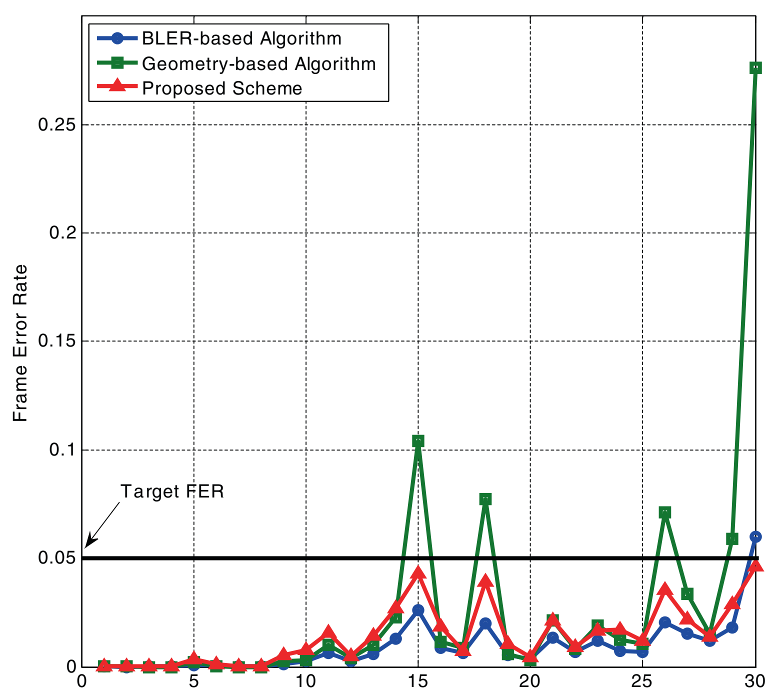

Figure 14 FER comparison when UE moves at 50 km/h.

3.3.3 Results of long-term QoS constraint (FER)

In CQI feedback point of view, feedback overhead of geometry-based algorithm is tiny since geometry-based algorithm only focuses on CQI feedback minimization. Figures 13 and 14 show the FER in system. The x-axis is a user index. User indexs are sorted in descending order of distance from the eNB. Since we assume that target FER is 5%, thus dropping of less than 250 frames has no influence on QoS. The proposed scheme and full feedback scheme are satisfying this constraint; however, geometry-based algorithm exceeds this tremendously in Figures 13 and 14. Full feedback scheme is most solid since all UEs feedback their CQI level to eNB at every frame, thus FER of full feedback scheme is 0%. Since geometry-based algorithm was designed under ideal assumption of static channel, this algorithm cannot adapt efficiently due to the variant of time varying channel as mentioned above. On the other hand FER performance of BLER-based algorithm is better than geometry-based algorithm, since BLER-based algorithm only focuses on FER minimization. However, BLER-based algorithm also cannot guarantee the target QoS requirements, 5%.

In these results, the proposed scheme reduces the amount of CQI feedback and simultaneously guarantees the QoS requirement of multicast services. That is, it achieves uplink resource efficiency and power saving of the UEs while guaranteeing the same image quality.

4 Conclusion

In this article, we have reported a novel multicast scheme for feedback-based multicast services over 3GPP LTE system. First, we analyze the proposed scheme by numerical method. The proposed scheme is formulated by discrete Markov process, and we can achieve the steady-state probability. Using these probabilities, we show how many CQI feedback bits will be reduced. Next, we analyze the proposed scheme by implementation method. We show that we are able to enhance the system goodput and also reduce CQI feedback while guaranteeing the same image quality compared with the full feedback scheme, geometry-based algorithm, and BLER-based algorithm. Hence, effective transmission and resource utilization will be possible in downlink and uplink streams, respectively.

Since the proposed scheme performs using only joining request, access granted, and CQICH messages, it does not need any additional control signal overhead. The proposed scheme can be expanded and employed in any kind of system, such as WCDMA, WiMAX, LTE, and LTE-Advanced.

There are many interesting refinements and extensions to this study. Particularly in the situation where the number of users far exceeds the number of CQICH, the proposed scheme would benefit from more active CQICH management by recalling CQICH to the receiver in an NFB state and reallocating this to other receivers in an FB state.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]School of Electrical and Electronic Engineering, Yonsei University, 134 Shinchon-dong, Seodaemoon-gu, Seoul, Korea. [2]Samsung Electronics Co., Ltd., 416, Maetan 3-dong, Yeongtong-gu, Suwon-si, Gyeonggi-do 443-742, Korea.

Received: 31 July 2012 Accepted: 14 November 2012
Published: 26 February 2013

References

1. U Varshney, Multicast over wireless networks. Int. J. Sci. Technol. Commun. ACM. **45**, 31–37 (2002)
2. A Chen, D Lee, G Chandrasekaran, P Sinha, in *IEEE International Conference on Proceedings of Mobile Adhoc and Sensor Systems (MASS), 2006*. HIMAC: high throughput, MAC layer multicasting in wireless networks, (October 2006), pp. 41–50
3. 3GPP, Multimedia broadcast/multicast service (MBMS); architecture and functional description, TS 23.246, 3rd Generation Partnership Project (3GPP), December 2009
4. J Chen, N Liao, Y Shi, J Li, in *6th IEEE Proceedings of Consumer Communications and Networking Conference, 2009, CCNC 2009*. Link adaptation for video multicasting in mobile WiMAX network, (January 2009), pp. 1–6
5. MR Chari, F Ling, A Mantravadi, R Krishnamoorthi, R Vijayan, GK Walker, R Chandhok, FLO physical layer: an overview. IEEE Trans. Broadcast. **53**, 145–160 (2007)
6. C Liang, NC Hock, Z Liren, in *International Conference on Communication Technology Proceedings, 2000. WCC—ICCT 2000*, vol. 2. Feedback suppression in reliable multicast protocol, (2002), pp. 1436–1439
7. MP Anastasopoulos, PG Cottis, High altitude platform networks: a feedback suppression algorithm for reliable multicast/broadcast services. IEEE Trans. Wirel. Commun. **8**(4), 1639–1643 (2009)
8. J Chen, N Liao, X Ma, in *IEEE Proceedings of Wireless Communications and Networking Conference, 2009. WCNC 2009*. A scalable feedback suppression mechanism for multicast service in wireless TDMA network, (2009), pp. 1–6
9. S Lu, Y Cai, L Zhang, J Li, P Skov, C Wang, Z He, in *IEEE 69th Proceedings of Vehicular Technology Conference, 2009. VTC Spring 2009*. Channel-aware frequency domain packet scheduling for MBMS in LTE, (April 2009), pp. 1–5
10. Y Cai, S Lu, L Zhang, C Wang, P Skov, Z He, K Niu, in *IEEE 69th Proceedings of Vehicular Technology Conference, 2009. VTC Spring 2009*. Reduced feedback schemes for LTE MBMS, (April 2009), pp. 1–5
11. 3GPP, Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures, TS 36.213, 3rd Generation Partnership Project (3GPP), December 2009
12. J Zander, S-L Kim, *Radio Resource Management for Wireless Networks* (Artech House, London, UK, 2001), pp. 347–361
13. J Kim, SH Moon, DK Sung, in *IEEE 16th International Symposium on Proceedings of Personal, Indoor and Mobile Radio Communications, 2005. PIMRC 2005*, vol. 3. Multi-QoS scheduling algorithm for class fairness in high speed downlink packet access, (September 2005), pp. 1813–1817
14. Y Xiang, J Luo, C Hartmann, in *Proceedings of European Wireless Conference*. Inter-cell interference mitigation through flexible resource reuse in OFDMA based communication networks, (April 2007)

doi:10.1186/1687-1499-2013-52
Cite this article as: Sohn *et al.*: **A novel multicast scheme for feedback-based multicast services over wireless networks.** *EURASIP Journal on Wireless Communications and Networking* 2013 **2013**:52.