Code Detection in a CDMA-based Common Channel

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***Abstract* — A CDMA-based common channel is a shared uplink channel that multiple users may send their event-specific CDMA codes to indicate their status. In such a channel, the base station may fail to detect a transmitted CDMA code due to the channel fading effect and the multiple access interference (MAI) resulting from the simultaneous transmission of the other CDMA codes. This paper presents system architecture to detect the transmitted CDMA codes in a CDMA-based common channel. A dynamic-threshold-setting method is presented to reduce the detection time and maximize the detection probability. A selective-retransmission method is further proposed to enhance the detection probability by exploring the time-diversity gain. Simulations results showed the proposed method may reduce the number of required radio resource units and achieve a low detection error probability than conventional methods. Hence, it could be a potential solution to reduce huge uplink singling overhead resulted from the simultaneous feedbacks from all multicast/broadcast subscribers.**

Keywords- CDMA; feedback; multicast and broadcast services (MBS); multiple access interference (MAI)

I. INTRODUCTION

A CDMA-based common channel is a shared uplink channel occupying a single radio resource unit. It allows multiple users to transmit event-specific CDMA codes to indicate their status. For example, a base station (BS) may reserve a set of CDMA codes and associate each code with a pre-defined feedback condition. The BS may issue a status query to all MSs. The query may be performed in a periodic or event-triggered manner. For each query, the BS broadcasts the intended feedback conditions and assigns a CDMA-based common channel (e.g., a time slot) for MSs to transmit their feedbacks. In response, each MS must transmit a CDMA code to indicate an ACK (or, NACK) if its corresponding feedback condition is met.

The CDMA-based common channel may be used to carry the feedback information sent from users subscribing a multicast and broadcast service (MBS). MBS is a point-to-multipoint service where data packets are transmitted simultaneously from a single base station (BS) source to mobile stations (MSs) via a common broadcast or multicast channel [1]. The spectral efficiency of MBS can be enhanced by adopting advanced features such as link adaptation and hybrid automatic retransmission request (HARQ) [1]. However, these advanced features rely on the feedback information provided by all of MSs, which leads to a very high signaling overhead in the uplink. Hence, there is still a strong debate on supporting these advanced features in MBS due to the concern of signaling overhead. With the common feedback channel, the BS may perform advanced features with affordable signaling overhead [2]. The CDMA-based common channel may also be used to reduce the signaling overhead required for counting users in MBS [3].

In such a CDMA-based common channel, the BS may fail to detect a transmitted CDMA code due to the multiple access interference (MAI) resulting from the simultaneous transmission of the other CDMA codes. The detection probability of a CDMA code is affected by near/far effects, fading of the wireless channel, and the MAI resulted from the other codes. In traditional CDMA systems, n CDMA codes are transmitted by n MSs. The BS knows the transmitted CDMA codes in prior [4-6] and utilizes stringent power control to combat near/far effects and fading [7]. The BS may further utilize multiuser detection (MUD) to cancel the MAI and thus, raise system capacity. Successive interference cancellation (SIC) is a simple and robust technique in doing the cancellation [4]. One approach of SIC uses the outputs of conventional correlation receiver to come out a gain list of users with nonincreasing strength. It successively cancels user interferences, ranked in order of received powers with the ranking obtained from correlations of the received signal with each user's chip sequence [7]. However, the iterative signal processing in the MUD/SIC will result in a long signal processing time and large accumulated detection errors if too many CDMA codes are used by the MSs.

Several MUD/SIC techniques have been proposed to deal with the MAI problem in traditional CDMA systems. In [4], the BS tried to reduce the MAI by minimizing the transmit power of all MSs. The transmit power was adjusted to ensure the same target bit error rate for all MSs. In [5], a site selection diversity (SSD) was presented to reduce the inter-cell interference and increase the uplink capacity. Transmit power control (TPC) was further used to combat the near-far problem and the multipath fading. In [6], two decision functions were proposed for multistage parallel interference cancellation (PIC). The linear decision cancellation is used if the signal amplitude estimation for each MS is small than the decision threshold value. Otherwise, a hard decision cancellation is employed. A network diversity multiple access (NDMA) was proposed to exploit the time diversity gain [8]. NDMA requests contending users to re-transmit collided packets and uses all of the received packets to calculate the collision-multiplicity (the number of contending users). Original packets are then recovered using source separation if all necessary retransmissions have been collected [8]. However, the NDMA protocols critically depend upon the accuracy of the collision-multiplicity detection [9].

In a CDMA-based common channel, each MS may transmit a CDMA code to indicate its status. Multiple MSs may simultaneously transmit the same CDMA code through

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the CDMA-based common channel. Different to traditional CDMA system, in which BS knows the transmitted CDMA codes in prior [4-6], the BS does not know the exact number of transmitted CDMA codes. Moreover, the number of simultaneously transmitted CDMA codes can be large. Therefore, existing power control and MUD/SIC techniques used in traditional CDMA system cannot be applied here. This paper presents system architecture to detect the transmitted CDMA codes in a CDMA-based common channel. The proposed architecture is composed of a decision-feedback-based MUD structure and a selective-retransmission structure. The decision-feedback-based MUD structure is used to reduce the MAI. A dynamic-threshold-setting method is then presented to reduce the detection time and maximize the detection probability of the decision-feedback-based MUD structure. The selective-retransmission controller is used to reduce the detection error resulted from fading. A selective-retransmission algorithm is then proposed to further enhance the detection probability.

The rest of this paper is organized as follows. The system model used in this paper is described in Section II. Section III exploits the details of the proposed solution. Simulations are conducted to verify the effectiveness of the proposed solution and the results are shown in Sec. IV. Concluding remarks are given in Section V.

II. System Model

Figure 1 shows a cellular system reserving a CDMA-based common channel for a set of *K* MSs. It was assumed that BS reserves *M* CDMA codes for MSs to indicate their status and the length of each CDMA code is *L*. Each CDMA code corresponds to a feedback condition. In this figure, the *j*th MS transmitting the *i*th CDMA code C_i, which is distorted by the channel fading effect h_{ji} and path loss d_j to the BS, $1 \le i \le M$, $1 \le j \le K$. The BS reserves an uplink CDMA-based common channel for gathering potential feedbacks from all MSs subscribing the same service. An MS shall transmit a CDMA code in the CDMA-based common channel if the corresponding feedback condition of the CDMA code is met. Different to NDMA, the collision-multiplicity is not known in prior since BS does not know which CDMA codes will be transmitted. In this paper, the inter-cell interference is neglected and it is assumed that MSs always use the maximum transmit power to send its CDMA code. Therefore, the received power of a CDMA code at the BS depends on the wireless channel condition and the number of MSs who transmit the same CDMA code.

Normally, the BS may use a correlator as a receiver and assume a CDMA code is detected if its correlation value exceeds a given detection threshold T_h. Let $C_i = [c_{1i} \quad c_{2i} \quad \dots \quad c_{Li}]^T$ be the *i*th CDMA code, where $c_{li} = \pm 1$, for $1 \le i \le M$, $1 \le l \le L$. Note that the cross correlation between CDMA codes is not perfect. That is,

$$C_i^T C_j = \begin{cases} L & \text{if } i = j; \\ < L & \text{otherwise.} \end{cases} \tag{1}$$

Before going into details, parameters used in this paper are summarized as below:

Y: A vector representing the received signal at BS.

M: Total number of CDMA codes.

K: Total number of MSs in a cell.

P_{ji}: Transmitted power of the *j*th MS, where $1 \le j \le K$. Note that

$$P_{ji} = \begin{cases} 1, & \text{if the } j\text{th transmit the } i\text{th CDMA code;} \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

d_j: Distance from the *j*th MS to BS, $1 \le j \le K$.

h_{ji}: Channel fading effect between the BS and the *j*th MS transmitting the *i*th CDMA code, $1 \le i \le M$ and $1 \le j \le K$. h_{ji} is a zero mean complex Gaussian random variable with unit variance.

N: A vector of independent zero-mean additive white Gaussian noise with power N_o and $N = [n_1 \quad n_2 \quad \dots \quad n_L]^T$.

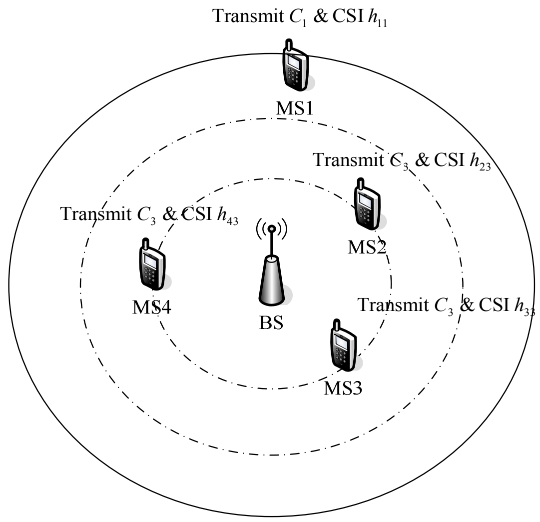

Figure 1. A cellular system which reserves a CDMA-based common channel for a set of *K* MSs..

The received signal at the BS is given by

$$Y = \sum_{i=1}^{M} \sum_{j=1}^{K} \sqrt{P_{ji} G d_j^{-\eta}} h_{ji} C_i + N = \sum_{i=1}^{M} h_i C_i + N. \tag{3}$$

where G is the antenna gain of the MS, η is the path loss exponent. Let $h_i = \sum_{j=1}^{K} \sqrt{P_{ji} G d_j^{-\eta}} h_{ji}$ be the total channel fading effect on the *i*th CDMA code, which include near/far effects, fading channel and can be found by channel estimation. In this paper, perfect channel estimation at the BS is assumed.

The performance of a detection technique may be characterized by the *false-alarm probability* P_f and the *missed-detection probability* P_m. The two error probabilities depend on the *decision threshold* (the value used by the algorithm to decide whether a signal is present or absent) [10]. A high decision threshold may reduce P_f but increase P_m. In this paper, a detection error probability P_e, which is the sum of P_f and P_m, is chosen as the performance metric.

The correlation value of the *i*th CDMA code, D_i, is given by

$$D_i = h_i^* C_i^T Y = |h_i|^2 L + \sum_{\substack{j=1 \\ j \neq i}}^{M} h_i^* h_j C_i^T C_j + h_i^* C_i^T N \tag{4}$$

The BS assumes that the *i*th CDMA code is detected if $D_i \geq T_h$. In the following, a dynamic-threshold-setting method is presented to minimize the detection time and maximize the detection probability. A selective-retransmission method is further proposed to deal with deep fading effect by exploring time-diversity.

III. Dynamic-Threshold-Setting and Selective-Retransmission

Figure 2 shows the proposed system architecture for detecting codes in a CDMA-based common channel. The proposed architecture is composed of a decision-feedback-based MUD receiver and a selective-retransmission (SR) controller. The decision-feedback-based MUD receiver is used to reduce the MAI resulted from the other CDMA codes. The selective-retransmission controller is used to reduce the detection error resulted from deep fading.

The decision-feedback-based MUD receiver contains functional modules of a *First Detection* module, a *Regeneration* module, a *Second Detection* module and a *Dynamic Threshold Setting (DTS) Controller* module. *First Detection* module is used to calculate the correlation value of the *i*th CDMA code D_i, $1 \leq i \leq M$. Initially, $T_h = T_{h0}$. T_{h0} was set to be a small value in order to minimize the missed-detection probability. However, a small T_{h0} may result in a higher *false-alarm probability* but it will be handled by *Second Detection* module as mentioned below. *Smart Sorter* in the *First Detection* module classifies the CDMA codes into a primary part (*PP*) and a secondary part (*SP*). *PP* consists of CDMA codes whose correlation values are larger than T_h. The remaining CDMA codes are kept in the secondary part (*SP*). Note that a smaller T_h may increase the size of *PP* and thus, reduce the detection time. *Regeneration* module is used to regenerate and cancel the signals of the CDMA codes belonging to *PP*. The correlation values of the CDMA codes in *SP* are expected to be increased after removing of MAI generated by codes in *PP*. Similarly, correlation values of the CDMA codes in *PP* are expected to be greatly reduced after removing codes in *PP*. Otherwise, the detected codes in *PP* may be wrong (i.e., false-alarm is occurred).

Second Detection module is used to calculate $D_i^{'}$ $(1 \leq i \leq M)$. $D_i^{'}$ is the correlation value of the *i*th CDMA code after canceling all of the CDMA codes in *PP*. In this module, it is assumed that a false-alarm is occurred if $D_i - D_i^{'} < T_d$, where $T_d = \gamma\, T_{h0}$ and $\gamma > 1$. *DTS Controller* module is used to increase T_h if any false-alarm is detected at the *Second Detection* module. The increasing of T_h may reduce the size of *PP*, which may decrease the false-alarm probability but at the cost of increased processing time.

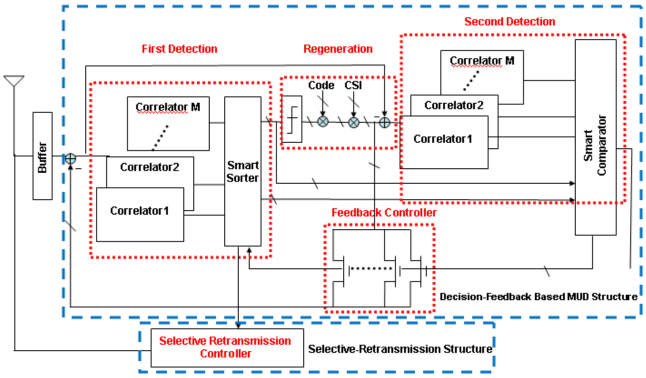

Figure 2. The proposed system architecture

SR Controller may request selected MSs to perform retransmission. Retransmission is a technique that utilizes time diversity to combat with the deep fading of the wireless channel. The degree of time diversity depends on the total number of radio resource used for the retransmission. *SR Controller* shall trigger a retransmission if $D_i \geq T_c$, for any $i \in SP$. Note that $T_c = \beta T_{h0}$ and $\beta < 1$. The BS shall announce the detected CDMA codes in its downlink message if a retransmission is triggered,. Note that the proposed retransmission method differs from NDMA [8], in which all MSs shall re-transmit packets based on the known collision-multiplicity. In this paper, only the undetected MSs (i.e., MSs whose codes are not detected by the BS) need to re-transmit the same CDMA codes in a newly assigned CDMA-based common channel. As a result, the MAI resulted from the detected CDMA codes will be disappeared after the retransmission. Therefore, BS may utilize the benefit of retransmission diversity to detect the undetected CDMA codes due to MAI or deep fading. Note that the BS may adjust T_c to improve the detection error performance at the cost of using extra uplink radio resource units. The maximum number of retransmission cannot exceed N_f.

The procedure executed in the proposed system architecture is summarized as follow:

Step 1: Set an initial value of the detection threshold $T_h = T_{h0}$ in the *First Detection* module.

Step 2: Calculate the correlation value D_i in the *First Detection* module based on Eq. (4).

Step 3: Find $PP = \{i \mid D_i \geq T_h\}$ and $SP = \{i \mid D_i < T_h\}$. Go to ***Step*** *7* if $PP = \varnothing$.

Step 4: Cancel the signal from *PP*. The output signal of the *Regeneration* module is given by

$$Y_c = Y - \sum_{i \in PP} h_i C_i = \sum_{i \in SP} h_i C_i + \mathrm{N} \qquad (5)$$

Step 5: Calculate the correlation value $D_i^{'}$ in the *Second Detection* module.

Step 6: Keep the detected CDMA codes obtained from *PP* if $D_i - D_i^{'} \geq T_d$ for all $i \in PP$, $Y = Y_c$ and go to ***Step 1***. Otherwise, increases the threshold value by $T_h = T_h + \alpha T_{h0}$, $\alpha < 1$, and go to ***Step 3***.

Step 7: *SR Controller* triggers a retransmission if $D_i \geq T_c$, for any $i \in SP$ and the total number of retransmission n_f does not exceed N_f (i.e., $n_f < N_f$). The MSs whose code are not detected shall retransmit the same CDMA code again. Update $n_f = n_f + 1$ and go to ***Step 1***.

IV. SIMULATION RESULTS

Snap-shot-based simulations were conducted on top of MATLAB to verify the effectiveness of the proposed method. In the simulations, performance metrics of detection error probability and the total number of radio resource used for retransmission were considered. In the simulation, a single cell with radius 800 *m* was considered. It was assumed that a total of K =100 MSs were uniformly distributed within the cell; each MS transmitted a CDMA code independently with probability P_{DT} and the CDMA code was randomly chosen from a total of M = 8 CDMA codes; and the perfect channel estimation was achieved at the receiver. The parameters used in the simulations $L = 144$; $\alpha = 0.025$; $\beta = 0.625$; $\gamma = 1.125$; $T_{h0} = 0.27L$; G = 1; and η = 2. Three schemes, MRU-FT, SRU-FT-R, and SRU-DT-R, were investigated. Among them, SRU-DT-R is the proposed solution; MRU-FT is the state-of-the-art solution; and SRU-FT-R is used to verify the effectiveness of the dynamic-threshold-setting method. In MRU-FT, the BS reserves *M* dedicated radio resource units (or, *M* dedicated channels) for MSs to transmit *M* CDMA codes and uses a fixed threshold value to detect the CDMA code received from each dedicated channel. A fixed detection threshold of $T_h = 0.35L$ was used in both SRU-FT and MRU-FT. There is no MAI effect in MRU-FT since each CDMA code is transmitted through a code-specific dedicate channel. In SRU-FT-R and SRU-DT-R, the BS reserves a single radio resource unit (or, a common channel) for MSs to transmit *M* CDMA codes. All MSs transmit their CDMA codes through the same common channel. The BS uses a fixed threshold value and a dynamic threshold value to detect the CDMA codes received from the common channel in SRU-FT-R and SRU-DT-R, respectively. However, the BS may request some MSs to re-transmit the same CDMA code depending on decision of *SR Controller*. Note that the maximum number of retransmissions is (*M-1*).

In Figs. 3 and 4, a low noise power of $N_o = -60dBm$ was investigated. In this case, the total received power of each CDMA code dominated the detection performance. Fig. 3 showed the detection error probability of the three schemes for different P_{DT}. A higher value of P_{DT} implies that more CDMA codes were transmitted, which results in a higher received power for each received CDMA code in both SRU-FT-R and SRU-DT-R. Therefore, the detection error probabilities of SRU-FT-R and SRU-DT-R were decreasing as the increasing of P_{DT}. It can also be found that the detection error probabilities of SRU-FT-R and SRU-DT-R were smaller than that of MRU-FT due to the benefit of retransmission diversity.

Figure 4 presented the mean number of used radio resource units for the three schemes as a function of P_{DT}. It was found in Fig. 4 that the mean number of used radio resource units in SRU-DT-R was almost invariant with P_{DT}. In contrast, the mean number of used radio resource units in SRU-FT-R was increased as the increasing of P_{DT}. It was because that the received power of CDMA codes may be higher if a higher value of P_{DT} was used. For P_{DT} = 0.1, the received power of CDMA codes in *SP* was not large enough to trigger the retransmission (i.e., $D_i < T_c$ for all $i \in SP$). Thus, the mean number of used radio resource units was small. In contrast, the received power of CDMA codes in *SP* was good enough to trigger retransmission when P_{DT} = 0.9, belong to *SP* are larger than T_c and triggered the retransmissions. Different to SRU-FT-R, the proposed SRU-DT-R may dynamically adjust the detection threshold. Therefore, SRU-DT-R can minimize the number of retransmission but achieved a similar detection error probability than SRU-FT-R did. From Figs. 3 and 4, it was further found that SRU-FT-R and SRU-DT-R have a similar detection error performance. However, SRU-DT-R used fewer radio resource units than SRU-FT-R did. It showed that the proposed dynamic threshold setting algorithm helps to reduce the number of retransmission and thus, minimize the used radio resource units.

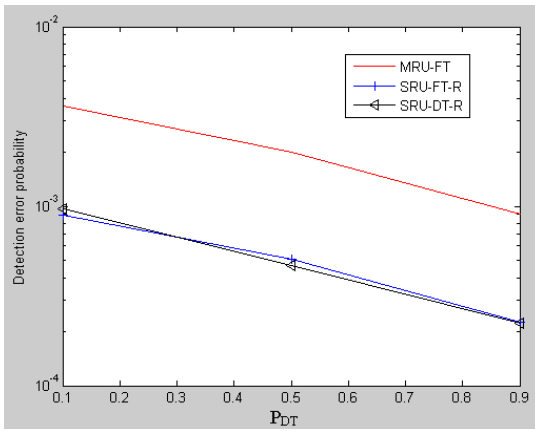

Fig.3. Detection error probabilities of the three schemes for different P_{DT}.

$P_{DT} = 0.3$ was considered in the simulations in Figs. 5 and 6. Fig. 5 showed the detection error probability for the three schemes for different noise power. It was found that the detection error probabilities of the three schemes were increased as the increasing of noise power. It was because that a higher noise power may results in a higher detection error probability. SRU-FT-R achieved a lower detection error probability than that of MRU-FT did. For a given detection probability, SRU-DT-R can have 6-8 dB gain than that of SRU-FT-R. Figure 6 showed the mean number of radio resource units of the three schemes for different noise power. It was found in Fig. 5 that the performance of SRU-DT-R and SRU-FT-R was quite similar. However, as shown in Fig. 6, SRU-DT-R required less resource units than SRU-FT-R did.

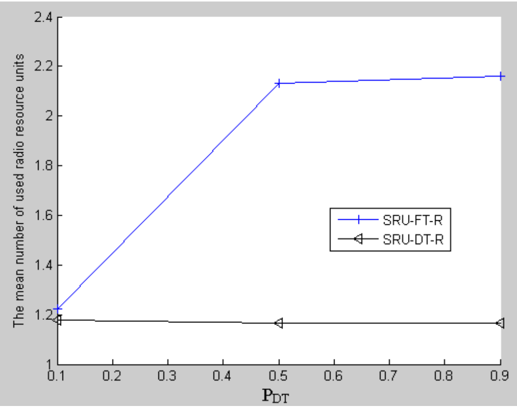

Fig. 4. Mean number of radio resource units used by the three schemes for different P_{DT}.

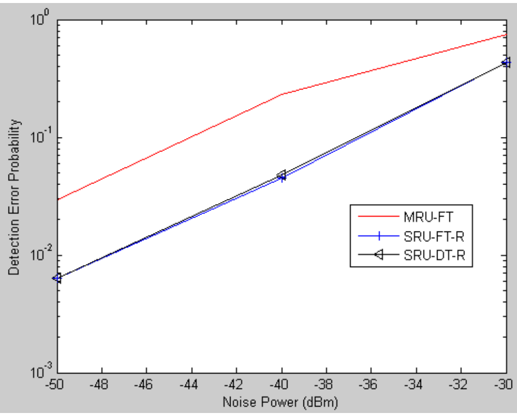

Fig. 5. Detection error probabilities of the three schemes for different noise power.

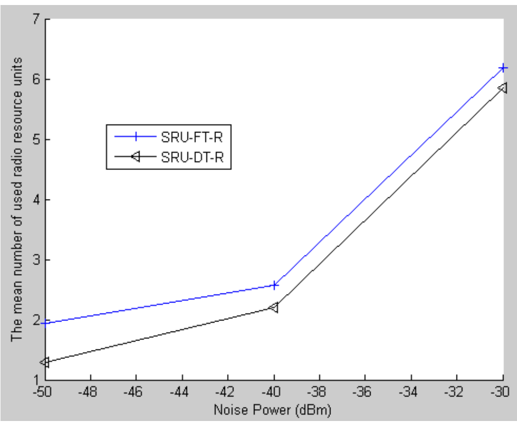

Fig. 6. Mean number of radio resource units used by the three schemes for different noise power.

V. CONCLUSION

This paper presents system architecture to detect the transmitted CDMA codes in a CDMA-based common channel. A dynamic-threshold-setting method is presented to reduce the detection time and maximize the detection probability. A selective-retransmission method is further proposed to enhance the detection probability by exploring retransmission diversity. Simulations results showed the detection error probability of the CDMA codes sent over the proposed common channel is much lower than that sending over multiple dedicated channels. The results also showed that the proposed dynamic-threshold-setting may help to reduce the number of retransmissions and thus, minimize the used radio resource units. Hence, it could be one of the solutions in dealing with the uplink signaling overhead problem resulted from MBS feedback.

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