A Compressed HARQ Feedback for Device-to-Device Multicast Communications

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Abstract—**An efficient receiving status feedback in multicast communications can improve the system performance considerably. In this paper, we propose a novel compressed hybrid automatic repeat request (HARQ) mechanism for the reliable multicast services in the cellular network controlled Device-to-Device (D2D) communications. Closely located D2D cluster devices transmit the acknowledgement and negative acknowledgement (ACK/NACK) message to a cluster head through D2D links directly, after that the cluster head feeds back the whole D2D cluster receiving status using 2-bit ACK/NACK to the cellular network. Performance analysis and numerical simulation results reveal that the proposed HARQ feedback mechanism is better than the conventional D2D multicast mechanisms in terms of the error probability and signaling overhead.**

Keywords-HARQ, ACK/NACK, multicast, feedback, Device-to-Device/D2D

I. INTRODUCTION

With the development of the cellular wireless networks (e.g. LTE, LTE-Advanced networks), especially the broadband service has increased significantly, the data traffic will be strong growth in the near future. It requires more efficient creative solutions for use of existing spectrum resources. Device-to-Device (D2D) [1]-[5] communications technology have been introduced as a beneficial complement of the IMT-Advanced system to reduce the overhead in the cellular communications, increase power and spectrum efficiency. So utilization of cellular controlled D2D communication can be necessary and applicable.

Cellular network controlled D2D communications reduce intercell interference to other users and arise new types of short range services and data intensive short range applications [3], e.g., D2D cluster multicast services. Typically an information sharing scenario: for an inter-cluster, D2D device exchanges information with its base station (also called evolved NodeB, eNB in the LTE architecture) via cellular links; for an intra-cluster, D2D communicates with each other directly via D2D links among a mount of geographically close devices (e.g., user equipment, UE), rather than via conventional wireless networks relaying. With the increasing demand on broadband applications in cellular networks, D2D direct communication and wireless multicast transmission service [6]-[9] are more and more popular. D2D multicasting in a cluster, can offer substantial gains [3], which is becoming an efficient way to improve the network throughput.

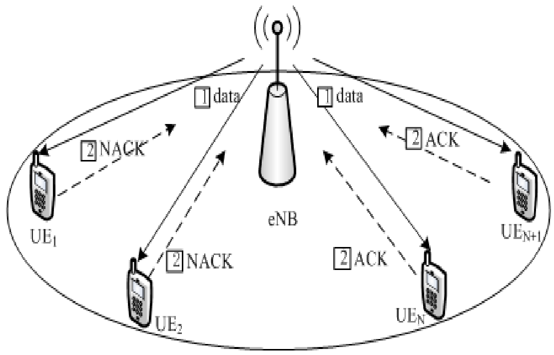

Figure 1. Simplified cellular HARQ process

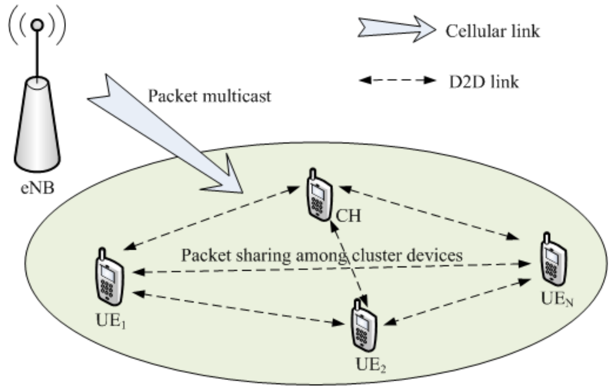

Figure 2. Scenario of D2D multicast communications

However, the received packet may be error in multicast communications, due to complex interference environment, so transmission reliability as one of the key challenges should be considered. Hybrid automatic repeat request (HARQ) is a very common and effective error correct mechanism in LTE. Fig.1 shows a simplified HARQ process in the cellular multicast communication in URTAN and E-UTRAN, eNB multicasting a packet to a cluster of UEs, some of the UEs receive the packet successfully while others fail. In the worst case, none of them receives the packet successfully. This receiving status is included in HARQ feedback message which is incorporated into the packet multicasting process, typically, the HARQ acknowledgement is packet wise, i.e. each UE reports its own

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acknowledgement and negative acknowledgement (ACK/NACK) message for each of the multicast packets to eNB; and eNB retransmits the packet if a NACK message is reported by the UE. On one hand, this cellular HARQ acknowledgement for requesting the retransmission or new transmission from eNB to each UE consumes significant signaling overhead and transmission power for UEs; on the other hand, D2D UEs in close proximity can directly communicate with each other and the D2D link is better than the cellular link [5] from the link quality and resource efficiency point of view, data packets and control signaling should be (re-)transmitted via D2D links as much as possible in D2D communications. However, the current cellular multicast HARQ process does not consider D2D specific characteristics yet. In this paper, we propose a novel compressed HARQ mechanism via cellular links to guarantee reliable delivery.

This paper is organized as follows. Section II reviews previous works related to multicast HARQ feedback and problem description, and Section III presents the compressed HARQ strategy and implementation. Performance analysis and simulation are given in IV. The final is conclusion.

II. PROBLEM DEFINITION

Considering the cellular network controlled D2D multicast system (see Fig. 2, which consist a single eNB and a cluster of devices UE_1, UE_2, UE_N and a cluster head UE CH), CH connects with cluster UEs via D2D links, and it also interacts information with its eNB via cellular links. In this case, in order to guarantee transmission quality, after eNB multicasting the packet to cluster UEs, a typical signaling and retransmission mechanism could be: the cluster UE or CH sends an ACK/NACK message to feedback receiving status to eNB respectively via cellular links. Then the CH or the cluster device with correct packet reception will retransmit the packet via D2D links. By that way, if there are N+1 (N is an integer) UEs (include the CH) in the cluster, there would be N+1 bits ACK/NACK information via cellular uplinks.

The other HARQ feedback mechanism is a NACK based feedback mechanism. If a UE within a cluster received the packet successfully, it does not send any feedback message. Only the NACKed UEs (the UEs failed to receive the packet) inform the NACK to CH via D2D links. Then joining its own receiving status, CH forwards all the HARQ feedback messages to the eNB via cellular links. Due to the receiving status of each UE is mapped one bit message, so even if all UEs receive the multicast packet successfully from eNB, N+1 bits feedback information is still needed via the cellular uplinks. Otherwise, even if only one UE failed to receive the packet, the intra-cluster HARQ feedback is also needed. Besides, if there is a UE failed to receive the packet, in case that the conventional NACK based feedback mechanism is adopted, eNB may need to inform which UE is responsible for the retransmission in the cellular downlink. Compared to the straight-forward cellular feedback mechanism, the NACK based feedback allows the UEs to exchange information through D2D links. However, either the former mechanism or the latter mechanism, the HARQ feedback signaling overhead increases in the cellular uplinks as the number of the UEs increases. As we know, the cellular uplink control signaling is very expensive and any extra uplink control signaling will degrade the network throughput, especially for a large scale networks. In order to solve this problem, maintaining a low uplink signaling overhead without degrading service reliability, we propose a novel compressed HARQ feedback mechanism for multicast communications in this paper.

III. COMPRESSED ACK/NACK FEEDBACK MECHANISM

In a cellular network controlled D2D communications, due to the dramatically changing radio links (the time-varying of wireless links), link quality is different for each device, even if these devices were located close to each other, packets receiving status may be different. D2D CH collects the receiving status information within a cluster via D2D links and reports it to the eNB via cellular links. First, within the cluster, only the NACKed UEs inform CH the NACK message, ACKed UEs and CH keep silence and monitor D2D links. Next, CH combines its own receiving status and forwards all the HARQ feedback messages to the eNB via cellular links, while all cluster UEs monitor the cellular link. Different from the conventional HARQ mechanisms, this paper proposes a compressed 2-bit HARQ signaling feedback mechanism via cellular links.

Considering the mobility characteristic of users, a cluster can be dynamic when UEs moves in and out. In this case, a CH maintains and updates its cluster until the cluster achieves a stable stage. Then it preorders all the D2D cluster devices, that is, all the cluster devices will be preordered based on any kind of decision criteria. The preorder of the devices can be assigned to each device implicitly or explicitly. It is a common decision mechanism, which can be defined in advance (standard-related due to different vendors) without extra signaling. For example, cluster devices could be ordered based on intra-cluster device ID, or based on order of joining the cluster, etc. As a result the D2D UEs can identify who should take the retransmission responsibility within a cluster when the CH fails to receive the packet, with no need for eNB to designate the retransmission sender. The overall transmission schedules are as follows:

Firstly, eNB transmits a multicast packet to a D2D cluster. Next, each cluster device and the CH receive the packet. If successfully receiving, the decision is ACK; else, the decision is NACK, after that, the cluster devices fail to receive the packet send NACK via D2D links, the CH and cluster devices received the packet successfully monitor. Then the CH categories the all devices receiving result into 4 cases, and sends overall receiving status representing the cluster via cellular links.

Case 1 All_ACK: All devices (e.g., UEs) and the CH receive packet successfully.

In this case, no cluster device sends NACK to CH, but monitors. As CH dose not receive anything in a pre-defined time interval, CH sends All_ACK via cellular link to eNB. eNB and cluster devices monitor. Then eNB will release the storage buffer and multicast the new packet. Correspondingly in case 1 of All_ACK, the cluster head and devices receive the new packet via cellular links as illustrated in Fig. 3(a).

Case 2 All_NACK: None of devices in the D2D cluster receives packet successfully.

In this case, the CH sends All_NACK via cellular links. Then eNB will multicast/ retransmit the same packet as illustrated in Fig. 3(b).

Case 3 Self_ACK: D2D CH itself receives packet successfully, and at least one cluster device fails.

In this case, the CH sends Self_ACK via cellular links, after that eNB can release the storage buffer for the original packet once it received Self_ACK, while the CH retransmits the packet via D2D links and NACKed devices receive as illustrated in Fig. 3(c).

Case 4 Self_NACK: D2D CH fails to receive a packet, at least one cluster device receives it successfully.

In this case, the CH sends Self_NACK via cellular links, and eNB can release the storage buffer for the original packet. The cluster devices received the packet successfully and highest order will retransmit the same packet via D2D links as illustrated in Fig. 3(d).

For the last two cases, after receiving the retransmitted packet, the NACKed UE will send the receiving status to CH as usual. CH will send one of Self_ACK or Self_NACK messages to the eNB (could be until the maximum number of retransmissions is reached or ACK is achieved).

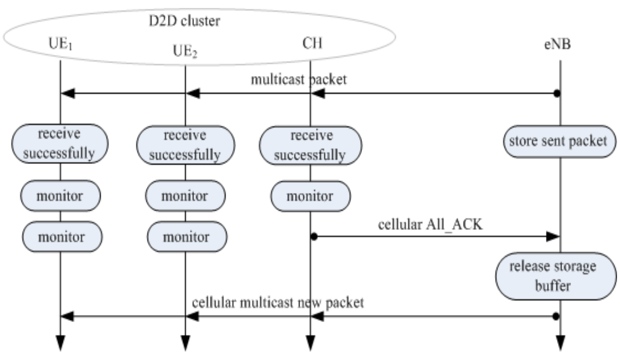
Table I gives one implementation example of four cases representing by only two bits.

TABLE I. ACK/NACK IMPLEMENTATION EXAMPLE OF 4 CASES REPRESENTING BITS

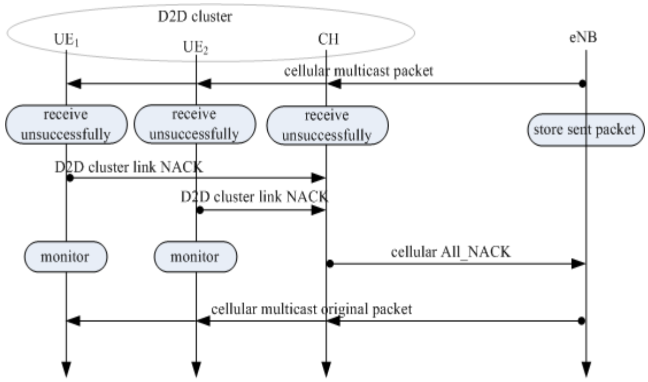
4 cases	**b(1)b(0)**
All_ACK	00
All_NACK	11
Self_ACK	01
Self_NACK	10

TABLE II. INTRA-CLUSTER HARQ STATUS

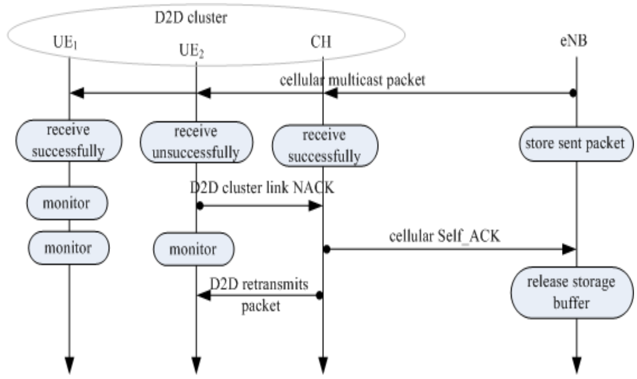
preordered cluster UEs	**UE_1**	**UE_2**	**UE_N**	**CH**
HARQ feedback	NACK	ACK	ACK	NACK



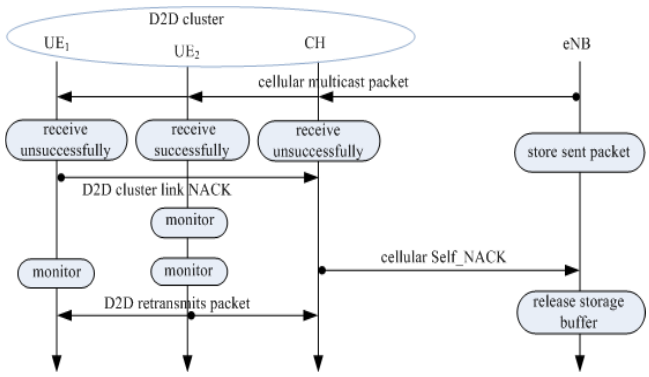
(a) CH sends All_ACK signaling



(b) CH sends All_NACK signaling



(c) CH sends Self_ACK signaling



(d) CH sends Self_NACK signaling

Figure 3. Proposed HARQ transmission mechanism

Note that, in Case 4, when the CH fails to receive the packet, and at least one cluster device receive packet successfully by preordering, the packet will be retransmitted among the cluster (not by CH), the cluster devices can decide by themselves who will be responsible to retransmit the packet within the cluster. Take Fig. 4 as an example, the receiving status is as illustrated in Table II, ACKed UEs (UE_2 and UE_N) are monitoring when NACKed UEs (UE_1) is sending the NACK to CH, then CH sends Self_NACK to the eNB. By the code division multiplexing (CDM) techniques as one of the options, the UE specific ACK can be distinguished at the receiving UE according to the UE specific code sequence information. Therefore, UE_2 can detect by itself that it shall retransmit the packet via D2D links according to the preordering of the UEs.

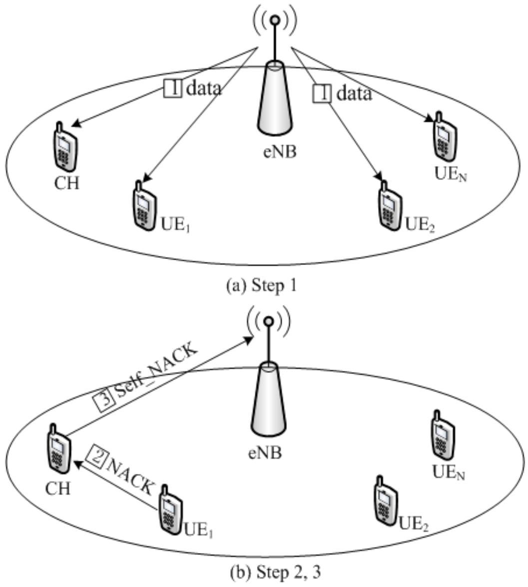


Figure 4. Simplified proposed HARQ transmission process

IV. PERFORMANCE EVALUATION

In this section, we investigate the HARQ performance of a typical information sharing scenario in Fig. 2, one eNB, N+1 D2D UEs (include a CH). The cluster is in a stable stage and its cluster UEs are ordered. In our proposal, within a cluster, it only requires NACKed UEs send NACK messages to the CH directly. That is, as long as the CH receives an, intra-cluster HARQ feedback message, it shall be a negative acknowledgement. So the CH can automatic correct intra-cluster HARQ feedback messages, without consideration of the decoding error of the D2D links, the intra-cluster HARQ feedback frame error is only related to the frames loss. Denote the HARQ feedback frame loss probability of D2D links in a cluster is q_1 ; on the other hand, with a inter-cluster, the cellular uplink HARQ feedback frame loss probability and the decoding error probability are p_1 and p_2 respectively through the cellular links. They are also conventional cellular uplinks HARQ transmission error probability. And the cellular downlink packets transmission error probability is p_d . So the total frame error probability of the proposed mechanism:

$$E\_proposed = 1-(1-q_1)^{p_d N}(1-p_1-p_2) \qquad (1)$$

Equation (1) is applicable for the NACK based feedback mechanism as well. However, since the cellular uplink signaling requires N+1 bits in the NACK based feedback mechanism, the total error probability would be higher than our proposal. Obviously, the performance of our proposal is better in the same condition.

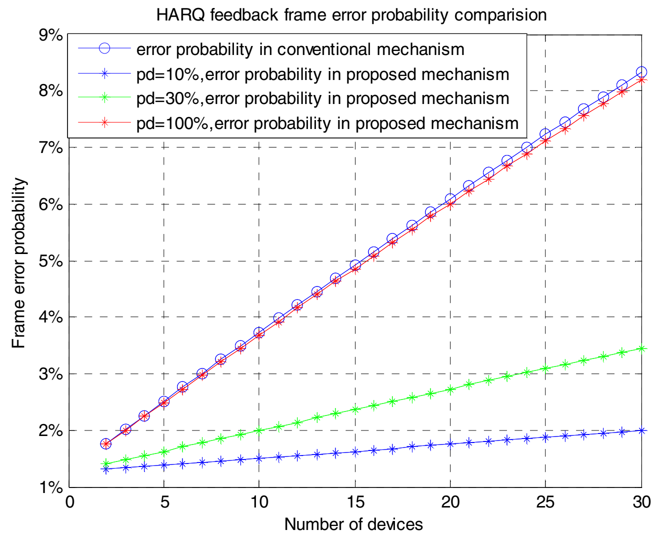
For the conventional cellular multicast uplink HARQ mechanism (see Fig. 1), after receiving the multicast data from eNB, all UEs feedback ACK/NACK messages to eNB, so the total HARQ feedback frame error probability of the straight-forward mechanism:

$$E\_traditional = 1-(1-p_1-p_2)^{N+1} \qquad (2)$$

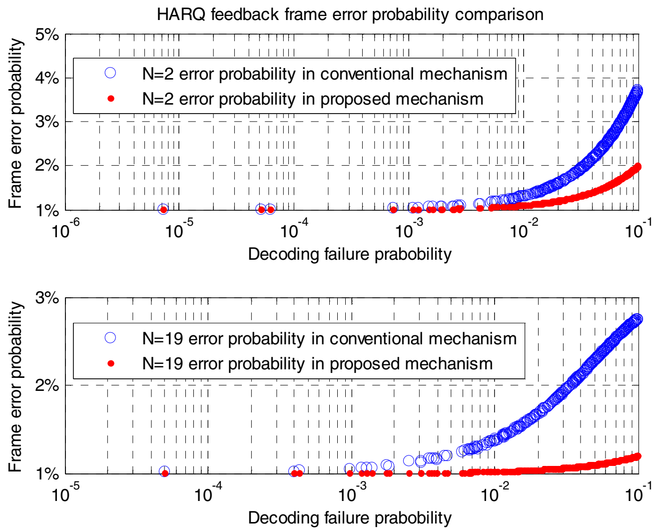
Generally, the D2D link is better than the cellular link [5], obviously $p_1 \ge q_1 > 0$ when the two links are using the same MCS and transmission power. Since the frame error probability is given by (1) increases as q_1 increases, let $q_1 = p_1$, the maximum frame error probability of the proposed mechanism can be also evaluated:

$$\begin{aligned} E\_proposed &= 1-(1-q_1)^{p_d N}(1-p_1-p_2) \\ &= 1-(1-p_1)^{p_d N}(1-p_1-p_2) \end{aligned} \qquad (3)$$

Fig.5 gives that the numerical simulation curves of the frame error probabilities of the two mechanisms while $q_1 = p_1$. Firstly, we can see that, for the same number of UEs, the frame error probability of the conventional cellular multicast mechanism is significantly higher than the proposed mechanism from Fig. 5(a). We also can know that the cellular downlink transmission quality affects the performance of our proposal, but without affecting the conventional mechanism. However, even in the worst case, when the cellular downlink packets transmission error is 100%, the performance of the proposal would be close to the conventional mechanism. Nevertheless, it is just a theoretical result which is not going to happen almost actually. Obviously, the performance of our proposal is better than the conventional mechanism. Next, Fig. 5(b) shows the frame error increase with the frame loss probability and the decoding error probability increase whether in conventional mechanism or in the proposed mechanism for the case of fixed UEs ($N = 2$ and $N = 19$ in Fig. 5(b)). In addition, when the numbers of the UEs increase, the frame error also increases, however, our proposed mechanism increased slowly.



(a)



(b)

Figure 5. HARQ feedback frame error probability for conventional and proposed mechanisms

Thirdly, we note that the proposed ACK/NACK feedback mechanism enables an intra-cluster retransmission whenever one cluster device or head receives the packet successfully, eNB can release the storage buffer for the original packet as early as possible, save buffer space. Last but not least, if no preordering, eNB has to select a UE to be transmitter for retransmission. The proposal does not need on retransmitting cluster UE assignment signaling for each retransmission any more by preordering.

TABLE III. SIGNALING OVERHEAD PER PACKET COMPARISON BETWEEN DIFFERENT MECHANISMS

Signaling overhead		D2D link	Cellular uplink
Conventional	Straight-forward	0	$N+1$
	NACK based	$0\sim N$	
Novel		$0\sim N$	2

V. CONCLUSIONS

In this paper we have investigated the two conventional HARQ mechanisms to support reliable multicast communications. As the uplink HARQ feedback result in an increased overhead consumption, we propose a compressed 2-bit HARQ feedback mechanism for D2D multicast communications. With the help of a D2D CH, the 2-bit information represents the overall receiving status of CH and all the D2D cluster devices to eNB. It mitigates the overhead consumption and the potential energy saving for cellular links. From the performance analysis and numerical simulation, the proposed method which outperforms the conventional mechanism in terms of the error probability etc, is an efficient HARQ feedback mechanism for multicast services. As further work, the preordered devices proposed in this paper could be implemented with additional simulations in dynamic clusters.

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