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Title	An ARQ scheme for IEEE 802.16j multihop relay networks
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Source(s)	Peng-Yong Kong, Derek Leong, Haiguang Wang, Yu Ge, Chee-Wei Ang, Chen-Khong Tham, and Wai-Choong Wong Institute for Infocomm Research 21 Heng Mui Keng Terrace Singapore 119613 Voice: +65 – 6874.8530 Fax: +65 – 6775.5014 Email: kongpy@i2r.a-star.edu.sg
Re:	Submitted in response to Call for Technical Proposals for IEEE 802.16j issued on 2006-10-15
Abstract	This contribution describes a cooperative ARQ scheme for relay stations as being defined in the IEEE 802.16j. It aims to improve the network performance through space time diversity. This is done by allowing retransmission of a failed packet being performed by an overhearing node, instead of the original transmitter node.
Purpose	The cooperative ARQ scheme is to be considered for Section 6.3.4.6 ARQ Operation.
Notice	
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Patent Policy and Procedures	

An ARQ scheme for IEEE 802.16j multihop relay networks

IEEE 802.16j is the IEEE standardization Task Group defining Mobile Multihop Relay (MMR) Specification for Broadband Wireless Access Systems. MMR is a promising solution to expand coverage and to enhance throughput and system capacity for IEEE 802.16 systems. It is expected that the complexity of relay stations (RS) will be considerably less than the complexity of legacy IEEE 802.16 base stations (BS). The gains in coverage and throughput can be leveraged to reduce total deployment cost for a given system performance requirement and thereby improve the economic viability of IEEE 802.16 systems. Also, relay functionality enables rapid deployment and reduces the cost of system operation. These advantages will expand the market opportunity for broadband wireless access.

Fig. 1 shows a typical usage scenario for MMR where a subscriber station (SS) is connected to the BS via one or multiple RS [1]. In this context, downlink transmission is from BS to SS and uplink transmission is from SS to BS. Thus, a RS will transmit for both downlink and uplink traffic compared to BS that can only transmit downlink traffic and SS that can only transmit uplink traffic.

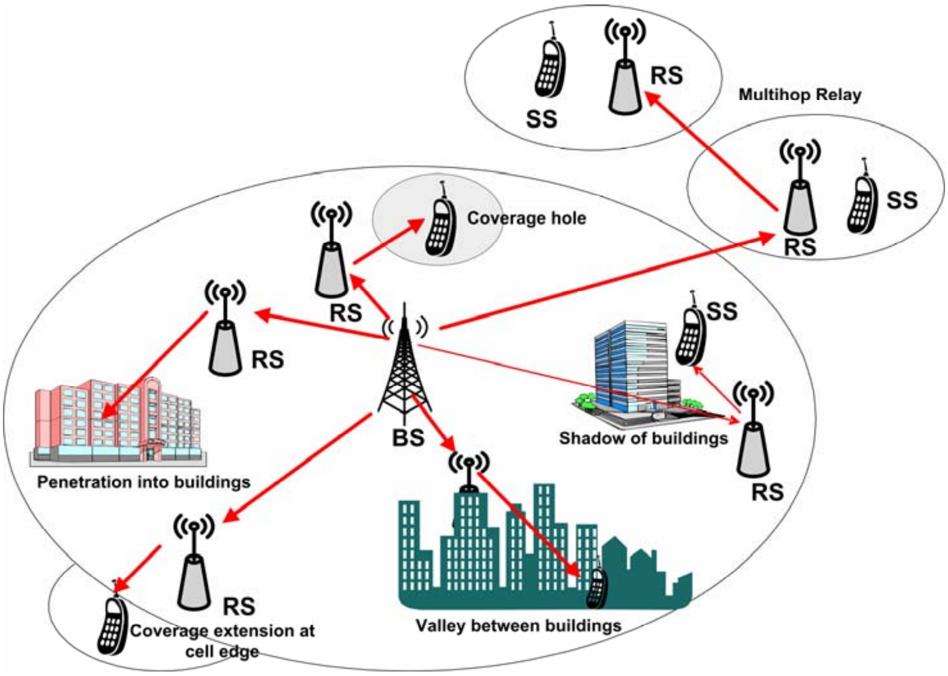

Fig. 1. A typical usage scenario of MMR

In downlink, as illustrated in Fig. 2, a transmission from BS to SS1 happens in two hops via RS1. In the first hop, transmissions from BS could be overheard by RS2 and RS3. Traditionally, when the transmission fails, BS is required to retransmit the failed packet. This may not be effective if the link between BS and RS1 is broken for an extended duration resulting in failures for all subsequent retransmissions. Since RS2 and RS3 have overheard the original transmission, they could effectively retransmit the failed packet on behalf of BS, and thus provide space time diversity. This retransmission from an overhearing RS could be sent directly to the SS1 if the overhearing RS is within the range of SS1. An example of this is given by RS2 in Fig. 2. If the overhearing RS is within the range of RS1 but not SS1 as illustrated by RS3 in Fig. 2, the retransmission will be sent to RS1. We call this cooperative retransmission because the overhearing RS and the original transmitter node are cooperating among themselves for a successful transmission. For simplicity, we call the overhearing RS or BS that helps in the retransmission the cooperative node. To realize the cooperative retransmission, we propose here a cooperative ARQ scheme. One requirement in IEEE 802.16j specification is that there will be no change to IEEE 802.16e SS [2]. Thus, our proposal introduces only changes to BS and RS but not SS, and operates on the link between non-SS nodes.

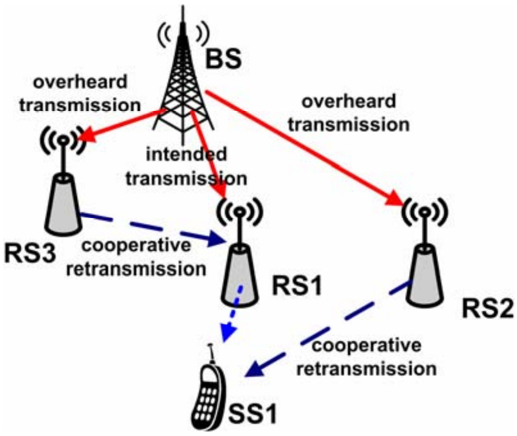

Fig. 2. An example of two-hop transmission between BS and a SS

When both the original transmitter node and the intended receiver node are not SS as illustrated in Fig. 3, C-NACK will be sent out by the intended receiver node when an erroneous packet is detected and there is an identified cooperative node. The C-NACK contains information indicating the identified cooperative node that should retransmit the failed packet and to which node the retransmission should be sent to. The cooperative node and receiver node are determined using Algorithm 1.

```
//Decision on performing actual or pseudo retransmission by the original transmitter node.
//Link quality is calculated as the ratio of total number of packets positively acknowledged
//over total number of packets transmitted. If the ratio is not more than 0.5, the link quality
//is consider bad.
if (link quality between original transmitter and intended receiver is bad)
    mode = 2;
else
    mode = 1;

//Decision on selecting cooperative node and receiver node.
//S_1 is the set of nodes with good link quality, and are within the range of the original
//transmitter node, the intended receiver node and the downstream node of intended
//receiver.
//S_2 is the set of nodes with good link quality, and are within the range of the original
//transmitter node and the intended receiver node.
// Q_{1,i} is the link quality between i-th node in S_1 and the downstream node of intended
//receiver.
// Q_{2,i} is the link quality between i-th node in S_2 and the intended receiver node.
// W_{k,i} is the willingness to cooperate as declared by the i-th node in S_k.
if (S_1 is not empty) {
    cooperative node = arg max_{i ∈ S_1} {W_{1,i} × Q_{1,i}};
    receiver node = downstream node of the intended receiver;
    }
else if (S_2 is not empty) {
    cooperative node = arg max_{i ∈ S_2} {W_{2,i} × Q_{2,i}};
    receiver node = intended receiver;
    }
else
    original ARQ procedure;
```

Algorithm 1. Decision algorithm for cooperative retransmission

The C-NACK is sent out using a C-ARQ IE with a format given in Table 1. Upon receiving the C-NACK, the cooperative node schedules to transmit once the overheard packet using the following scheduling algorithm.

```
generate a random number x within the range and inclusive of 0 and 1
if (x ≤ P1 and own packet queue is not empty)
        transmit own packet;
else if (x ≤ P1+ P2 and retransmission queue is not empty)
        retransmit own failed packet;
else if (x ≤ P1+ P2+ P3 and identified as cooperative node and the failed packet is buffered)
        retransmit overheard failed packet;

// P1+ P2+ P3 = 1
// P1 ≥ P2+ P3.
// Suggestion: P1 = 2 × (P2+ P3) and P2= P3
```

Algorithm 2. Scheduling algorithm for cooperative retransmission

On the other hand, the original transmitter node will enter the "waiting for retransmission" state as illustrated in Fig. 4 which is a modification from Figure 33 in the current IEEE Standard 802.16 specification document [3]. In this state, the scheduling for retransmission is performed using Algorithm 1. To transition from this state, there are two modes of operation, namely mode 1 and mode 2. In mode 1, the original process is followed. In mode 2, the original transmitter node will transition to the "outstanding" state following the normal process which includes starting the ARQ_RETRY_TIMEOUT timer but not actually transmitting the packet. This process of pretending retransmission at the original transmitter node is labeled as "Pseudo Retransmit" in Fig. 4.

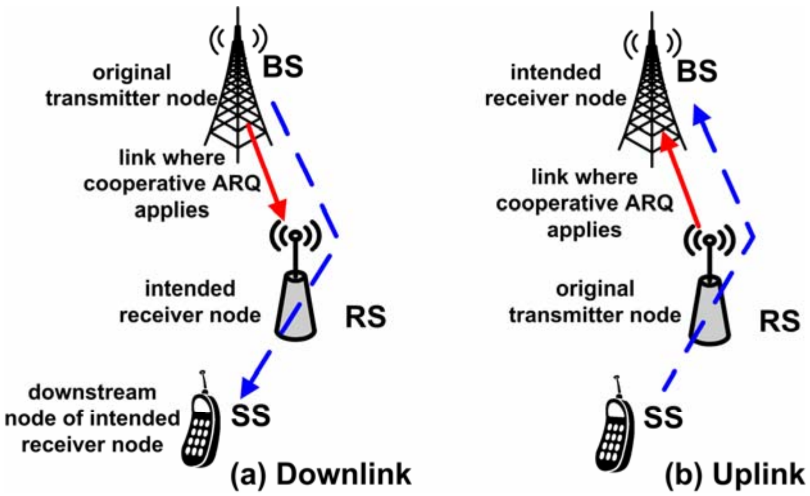

Fig. 3. Links where cooperative ARQ is applied

If ARQ_RETRY_TIMEOUT timer expires without any negative acknowledgment received as illustrated in Fig. 5, the original transmitter node may decide to retransmit the failed packet or delegate the retransmission to a cooperative node. In both cases, as illustrated in Fig. 4, the node will enter "waiting for retransmission state" eventually. If the retransmission is delegated, the node will immediately send out a C-ARQ Command using the C-ARQ IE before entering the "waiting for retransmission" state. The C-ARQ Command indicate the cooperative node that should retransmit the failed packet and to which node. Upon receiving the C-ARQ Command, the cooperative node schedules to transmit once the overheard packet using Algorithm 1.

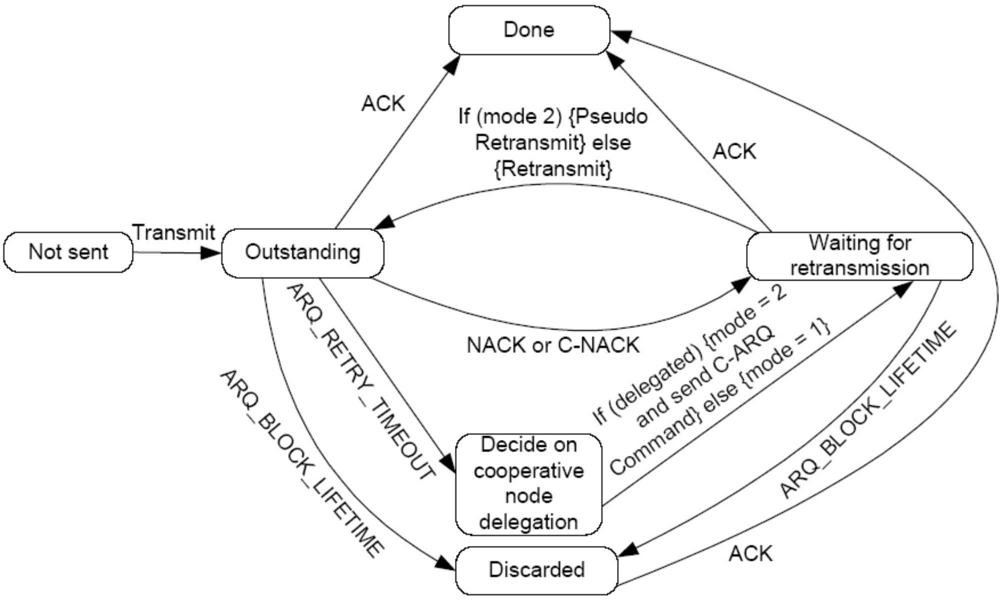

Fig. 4. C-ARQ transmit block states

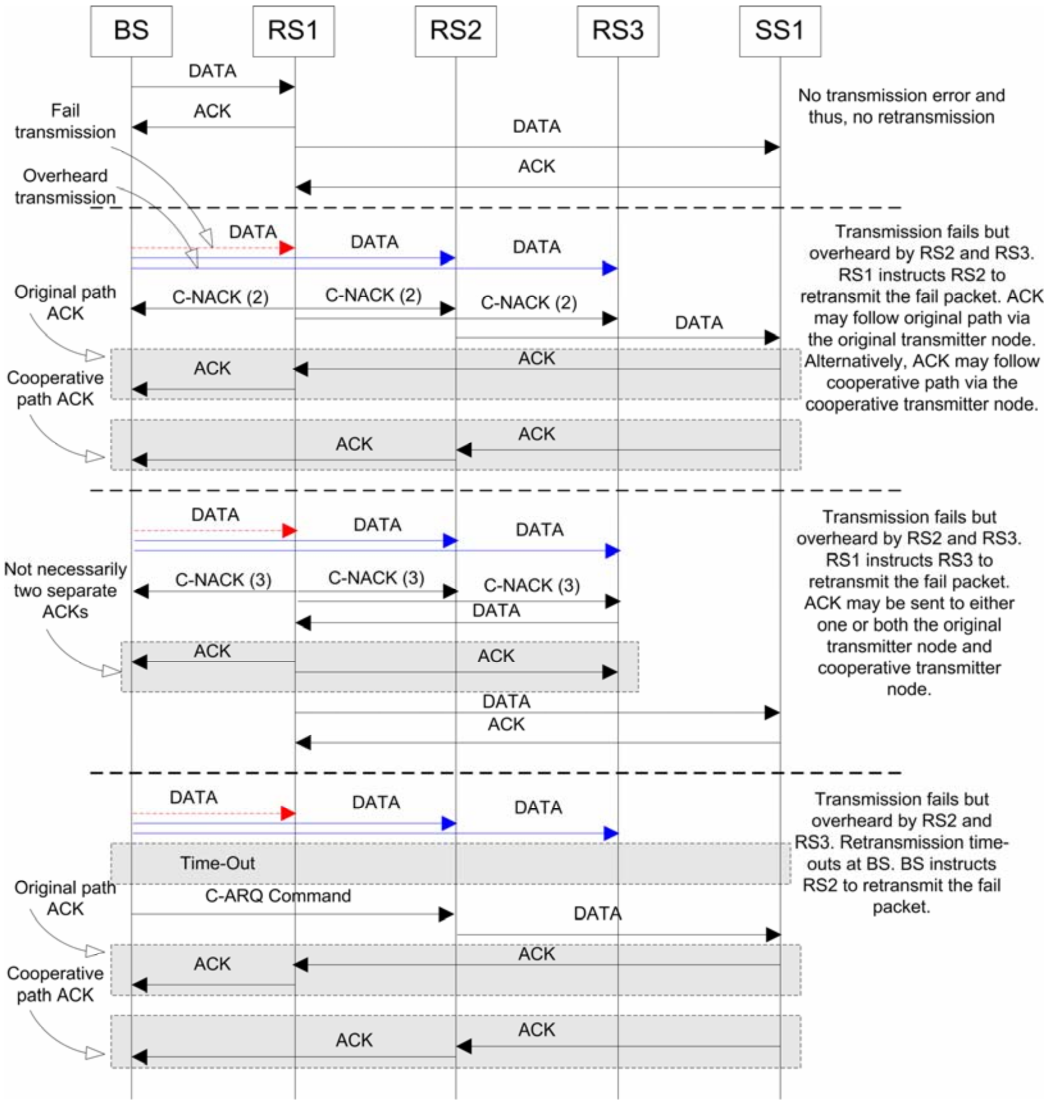

Fig. 5. Examples of packet exchanges in C-ARQ based on topology in Fig. 2

Syntax	Size	Notes
C-ARQ_IE(LAST) {	*variable*	
COOPERATIVE NODE	16 bits	The identified Cooperative Node
LAST	1 bit	0 = More C-ARQ IE in the list 1 = Last C-ARQ IE in the list
TYPE	2 bits	0x0 = C-ARQ Feedback (C-NACK) 0x1 = C-ARQ Command 0x2 = reserved 0x3 = reserved
CID	16 bits	The ID of the connection being referenced
BSN	11 bits	Block Sequence Number
MODE	2 bits	0x0 = reserved 0x1 = Not Pseudo Retransmission 0x2 = Pseudo Retransmission 0x3 = reserved
RECEIVER NODE	16 bits	The identified Receiver node
}		

Table 1. C-ARQ IE

References:

[1] "MMR Harmonized Contribution on 802.16j (Mobile Multihop Relay) Usage Models", *Document No. IEEE 802.16j-06/015*, 05 September 2006.

[2] "P802.16j - Amendment to IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Multihop Relay Specification", March 2006.

[3] "Part 16: Air Interface for Fixed Broadband Wireless Access Systems", *IEEE Std 802.16-2004*, October 2004.