Fluctuation Request: A Fast Retransmission Scheme in Power Line Communication Network

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Abstract — **Broadband power line communication (BPLC) access technology provides high speed data transmission capability for multimedia service in digital homes. However, because of the frequency and time-varying characteristics of the power line channel, unpredictable packet loss happens during service transmission; in order to guarantee the requirement of QoS and improve the throughput performance, an effective approach is to retransmit the lost packet by the NACK message indication. This paper proposes a fast retransmission method named fluctuation request, wherein the internal node located along the transmission path is invited into the work of retransmission. The algorithm is designed to work in the system suffered with burst or constant packet loss. Comparing with the traditional method that totally relies on the source node for the data retransmission, the proposed mechanism can reduce the retransmission step and improve the average target packet hit rate for both unicast and multicast services.**

Index Terms – **Power Line Communication, retransmission, NACK**

I. INTRODUCTION

Digital home networking to transmit high quality audio/video service is the most promising application scenario for power line communication network. One obvious advantage is the installation cost saving resulting from the usage of the existing low-voltage cable and AC outlets, furthermore, the development of power line communication standards such as HomePlug AV[1] and Open PLC European Research Alliance(OPERA)[2] boost the achievable data rate up to 200Mbps in physical layer by employing the advanced PHY and MAC layer technologies. However, the sensitive indoor power-line channel is a frequency selective fading channel with time-varying characteristics. The background noise and impulsive noise generated from the switching of electrical appliances could cause different types of interference [3], the other impact comes from the multi-path response corresponding with the power cable layout and loading conditions [4]. An obvious phenomenon is the sporadic or burst packet loss will happen when such unpredictable interference emerges. Even in a stable transmission environment, the behavior of packet loss in PLC network has two unique features under various traffic loads based on the filed test in [7]:

(a) The packet loss rate could be very small if the running traffic is light loaded;

(b) The packet loss rate increases significantly once the sending rate rises to some threshold value. Such threshold may have great variation under different connection topology when interference exists.

In recent years, some QoS enhancement technologies for reliable video transmission through PLC network are proposed. Most of them focus on the employment of forward error correction (FEC) in application layer [5], and the method to deploy multiple description coding [6][8] is also explored. Because these two approaches both require adding redundant information into the service stream for robust data transmission when partial information is lost, thus the transmission efficiency will be affected significantly due to the packet loss feature (b) mentioned above, especially when packet loss rate is ascending. The added redundant data will augment the overall traffic load, leading to more severe packet loss when the threshold value is achieved. Therefore, the supplement of the redundant data is only suitable for the scenario where the average packet loss rate is low and enough free bandwidth is available for redundant packets transmission.

Another type of approach is to improve the performance of CSMA/CA protocol deployed in PLC network to solve the interference problem. Literature [10] proposed throughput enhancement techniques by simply modifying the collision avoidance algorithm in CSMA/CA. Paper [11] presented a throughput optimization algorithm with the precondition that each station always knows the exact number of collection station in its neighboring range. These researches assumed the channel is ideal without transmission error in the channel and the transmission error is only caused by packet collision, which can not reflect the real situation of power line channel. Some rate adaptive schemes are provided either by real-time signal detection [12] or the integrated channel condition report in the NACK/ACK message [13], wherein the retransmission work is done by source node only and the loss probability of acknowledge message is not considered.

In this paper, we focus on the problem of lost packets retransmission in the PLC network for both unicast and multicast services. In traditional retransmission mechanism, take ARQ (Auto Repeat reQuest) for example, the receiver sends out acknowledge signal

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(NACK) when current packet is lost; on the other side, the source node is configured to transmit the requested data block. In order to improve the retransmission efficiency, we propose a fast retransmission mechanism named fluctuation request. Compared with traditional retransmission method, the difference is introducing the internal node ,near to the destination node, to join the retransmission function when the bypass NACK is captured. The fluctuation means before the sender gives feedback to the retransmission request, the internal node will intercept the request and regenerate a new one if the queried packet is not found in its local buffer, just like the wave diffuses in the water across some barriers. Generally speaking, the channel condition between the internal node and destination node is better than that between source node and destination node because of shorter transmission distance and lower interference. Consequently, the lost packet hit rate will increase and the step of retransmission will reduce. In addition, the proposed mechanism can be easily extended to multicast transmission by selecting one indication node as an agent to send NACK message, then fulfilling retransmission from one selected internal node to all receivers in the same branch, thus a balance of robust transmission and light-weighted message exchange is achieved. If the feedback overhead is ignored, a more comprehensive extension is designed to allow each receiver send request following some sequence rule, so that the lost packet can be retransmitted as much as possible.

The rest of this paper is organized as follows: Section II reviews the packet loss pattern in the indoor power line environment. The mathematical analysis of problem is described in Section III. The detailed scheme and algorithm description for the proposed fast retransmission mechanism are presented in Section IV with the case study in unicast and multicast transmission. The detailed simulation results are shown in Section V including the comparison of performance with traditional method. Finally, a conclusion is given in Section VI.

II. PACKET LOSS PATTERN IN THE POWER-LINE ENVIRONMENT

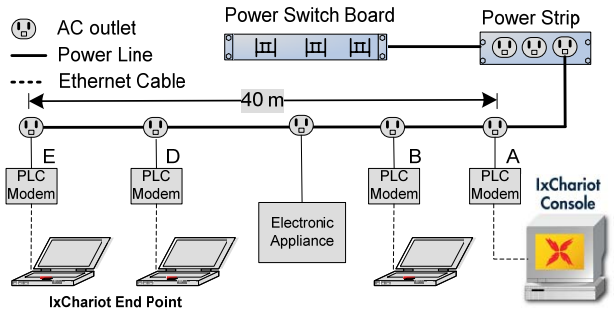

Fig. 1 Test environment of PLC network

In [7], only two PLC modems are used in the test environment, we extend this experiment by adding more PLC modems into the transmission path. As shown in Fig.1, one source node and three destination nodes are placed along a power line cable, each node connects to a PLC modem. In each round of testing, the source node transmits data to the receiver node at designated sending rate generated by IxChariot console software. The packet size is fixed as 1024 Bytes and the UDP streams are deployed to explore the packet loss behavior under different traffic load. In each round of testing, a peer of source node and destination node is selected with different transmission distance along the power line connection.

The packet loss rate between peers with different sending rate is summarized in Fig.2, two conclusions can be made from the results as follows,

(a) For each transmission between two modems, the packet loss rate increase significantly when the source sending rate exceeds the threshold value, this conclusion has already been mentioned in [7];

(b) Under the same sending rate, the packet loss rate varies a lot among different peers. For example, when sending rate is 65Mbps, there is nearly no packet loss between modem A and B, and there is nearly 2% packet loss between modem A and D, but the packet loss is higher than 10% between modem A and E. The reason is data transmission through longer path has great probability to meet packet loss caused by traffic congestion and noise interference.

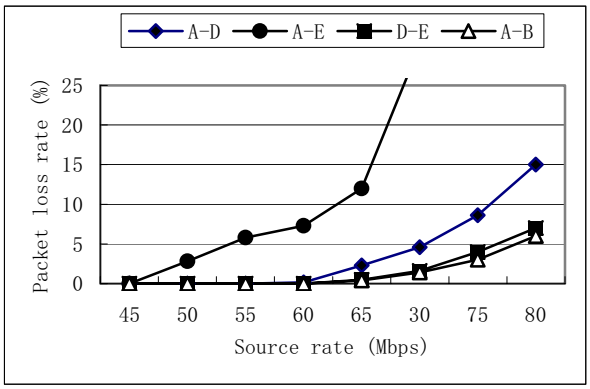

Fig. 2 Packet loss rate under different source rate

Although some bandwidth estimation mechanism can be deployed to scan the available bandwidth before data transmission then dynamically adjust the service rate in the source node, it can not guarantee the zero packet loss in the time-vary power line channel because of the following three constraints:

(a) Bandwidth estimation is only suitable for unicast service, it can not be deployed in multicast or broadcast service wherein multiple receivers exist;

(b) The accuracy of bandwidth estimation based on the calculation of packet loss rate in the upper layer depends on the time duration of ACK interaction under passive mode and the response of probing packets in the active mode, there is still packet loss during the interval of source rate adjustment;

(c) Many high quality video based applications require sustained bandwidth guarantee, such as HDTV. If the transmission rate for video streaming is cut down following the variation of channel condition, the visual quality declines at the same time.

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III. MATHEMATICAL ANALYSIS

A linear model is created for the theory analysis. As shown in Fig.3, the node with label *S* is the source node, *D* represents the destination node, and node *I* is the internal node, which will send out response when capturing the NACK indication from the receiver. p, p_a, p_b are different packet loss rates among the connections. Based on the result of field test, there is a conclusion that

$$p_a + p_b < p \quad (1)$$

under the same source rate.

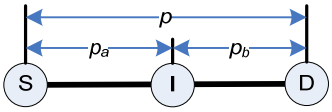

Fig. 3 Linear model

To simplify the analysis, the efficiency of one time retransmission is compared. Assuming in receiver side, there is one unit packet loss in last transmission, it will send out one unit NACK indication message. In the traditional way, the probability of target packet hit rate ($TPHR = \frac{\text{Number of receiving packet at destination node}}{\text{Number of original packet at source node}}$) of retransmission is $TPHR(old) = (1-p)^2$; the calculation of hit rate for the proposed mechanism is $TPHR(proposed) = (1-p_b)^2(1-p_a)$, where $(1-p_b)^2$ is the NACK and data packet loss probability between node *I* and node *D*. $(1-p_a)$ is the matching probability of requested packet in the data buffer of node *I*.

To compare the variation of above *TPHR*, we define two variants x, y during the calculation. $p_a = x * p$ and $p_b = y * p$, according to the constraint (1), we can get

$$0 < x + y < 1, \; and \; 0 < x, y < 1 \quad (2)$$

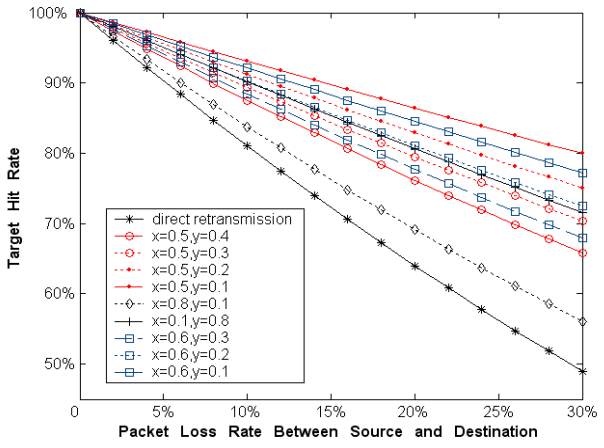

Fig. 4 Target packet hit rate

Fig.4 shows the *TPHR* comparison under different combination of (x, y). The x-label represents the packet loss rate p between the source and destination node. The scenarios can be divided into three categories:

(a) Internal node is near to the source node, for the case when x=0.1 and y=0.8;
(b) Internal node is near to the destination node, for the case when x=0.8 and y=0.1;
(c) Internal node is in the middle, for the case when x=0.5 and y=0.4

It is obvious that no matter where internal node is placed, the proposed mechanism can always achieve higher *TPHR* than the traditional method.

IV. PROPOSED RETRANSMISSION MECHANISM

A. Scheme Description

In the PLC network, a transmission path is predetermined before the start of communication, and the network topology will not change during the service transmission. In addition, the information of terminals can be obtained manually by network administrator or automatically by the neighbor discovery message broadcasting. On the other hand, PLC is a shared media system, all the internal nodes located along the transmission path between the source and destination node can catch the data and signal packets in MAC layer, but none of them contribute to the retransmission work in the conventional power line modems.

As shown in Fig.2, if the retransmission is happened between node D and E, the target packet hit rate (*TPHR*) is higher than the same operation between node A and E because of the better channel condition. According to the definition of *TPHR*, higher *TPHR* value means more data packets arrivers at destination node, corresponding with better data integrity. So we proposes a mechanism to allow internal nodes to join the work of retransmission, which is composed of 2 steps as follows,

Step1 involves the transmission sequence determination based on the topology and the service session allocation. To simplify the explanation, we define two types of internal node as follows:

(a) 1st node – the 1st nearest node to the receiver;
(b) 2nd node – the 2nd nearest node to the receiver.

For unicast service, if there are equal or more than two internal nodes located in the transmission path, the 1st and 2nd node will be assigned directly, if there exists single internal node, only 1st node will be labeled. For multicast service, if all the receivers are located in the same branch, the node with the longest distance from the sender will be selected as the node to send NACK indication during transmission, the assignment of internal nodes follows the same policy for unicast service. If the receiver nodes are distributed in different branches, the selection of longest distance node and the assignment will be done separately in each branch.

Step2 includes the algorithm for retransmission processing. To constrain the latency, the request for the retransmission of one lost packet can be done at most three times. When the receiver sends out NACK signal, there is an index to tell the time sequence for the request, then different internal node or source node will send out the buffered data if necessary. As shown in Fig.5 when

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the receiving terminal sends out the first NACK (sequence=1) for data block #1, the 1st node will be assigned to retransmit the data block #1 to the receive; if this time of retransmission fails, the 2nd node will do the same thing as long as it receives the second NACK (sequence=2) for data block #1. The source node is in charge of the response for the NACK with sequence number equal to 3 for a final try. Because in each time of retransmission, only one node (either internal or source) could send out the requested data block, there will be no interference during retransmission.

Normally, in the MAC protocol of power line communication, both Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) allocation modes are supported. The retransmission can be scheduled in the contention free time slot in the TDMA or non-conflict frequency in the FDMA, so that there are no multiple copies of the same packet during retransmission.

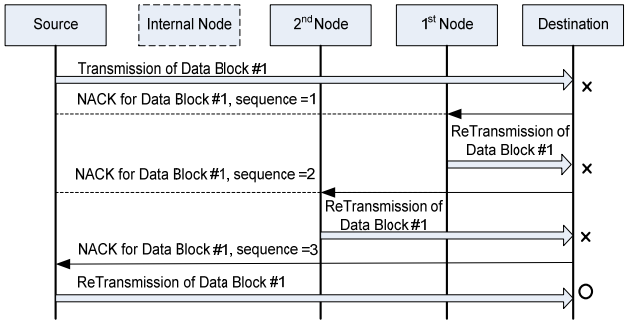

Fig. 5 Process flow of the proposed mechanism (unicast scenario)

For multicast service, most existing multicast protocols such as reliable multicast transport protocol (RMTP)[9] adopt a static retransmission scheme (by creating multiple unicast sessions or a new multicast session) to retransmit lost packets; such static unicast mode may result in large amount of duplicated traffic in retransmission, while the multicast mode will cause the variation of data recovery accuracy among receivers.

To support multicast transmission, we propose two approaches in accordance with the different feedback overhead. The first one is called fluctuation request—simple request (FR-Simple), wherein only one assigned indication receiver can send out the NACK signal in each route branch, and the retransmission will be processed in each branch respectively. To simplify the problem, at most two times of request for one lost packet is allowed. Although such multicast request scheme can reduce the complexity scheduling algorithm in head end, the drawback is the selected representing receiver may not reflect the actual packet loss situation of other receivers belonging to the same multicast group. A more comprehensive method is to allow all receivers to send NACK request in some pre-defined sequence. We call it fluctuation request—full request (FR-Full). Considering the propagation feature in the PLC channel, if the packet loss happens in the receiver near to the source, it is very possible that other receivers located in the same branch will also miss this packet. Therefore the sequence to send NACK can be assigned based on the distance (hop count) to the source node among all receivers. Fig.6 shows an example with 3 receivers in a branch, assuming data block #1 to block #3 suffer different packet loss during transmission. As far as hop count from source node is considered, receiver1 owns the shortest distance, so it has the chance to send NACK firstly; As a response for this NACK, source node will retransmit the data block #1, since such retransmitted block can also be received by other node along the transmission path, the packet loss for data block #1 will be automatically recovered in receiver2 and receiver3, thus the request for block #1 in receiver2 and receiver3 will be removed. In this example, receiver3 is the farthest node, when it sends out the NACK request, the process will be the same as that under unicast scenario, the internal node will join the retransmission work to improve the efficiency. In order to reduce the latency, in multicast transmission, only the 1st nearest node will give response for each NACK request.

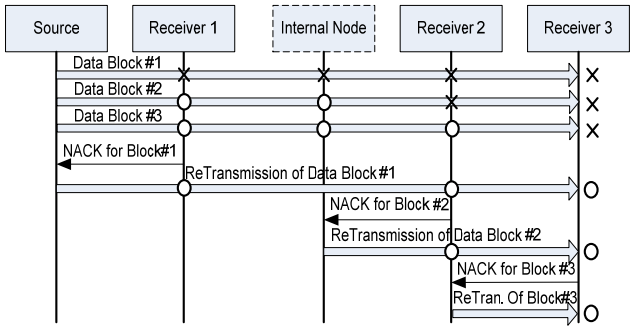

Fig. 6 Process flow of the proposed mechanism (multicast scenario)

B. *Algorithm Description*

The flow chart of the retransmission algorithm for unicast service is shown in Fig.7, the 1st node is selected for case study. The initial process will determine the role of retransmission node (the 1st or 2nd node) with index in the transmission path, and the service session information will be broadcasted through the path to let each selected node know which session it should work for; afterward, these active nodes scan channel and capture passing packets. For data packets to itself, destination address will be checked and the normal packet processing such as integrity checking, refragmentation, payload filtering will be fulfilled. For those data packets in the target service session, they will be stored in the local buffer in the queue labeled by its destination. The buffer depth can be set dynamically based on the type of service.

For the NACK signal packet from the destination node, the sequence number is parsed to determine which time of request it is. If the sequence number is larger than 2, meaning this packet has already been re-requested for many times, it would be the source node to do the retransmission; otherwise, local label will be compared with the sequence number to determine whether or not to give response. The following steps include searching in

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the buffer to check whether the data block indicated in the NACK is existed. If so, this block will be sent out in the next re-transmission time slot. If there is no such data block found, a new NACK message will be generated with sequence number plus one.

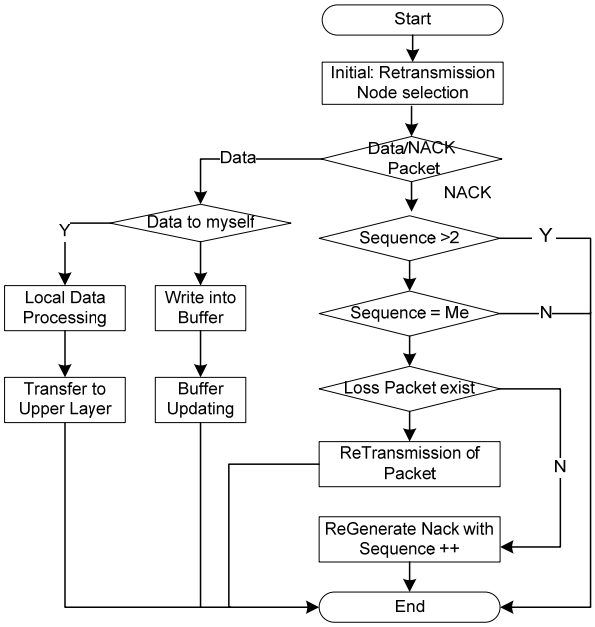

Fig. 7 Flow chart of the proposed mechanism (in the 1st node)

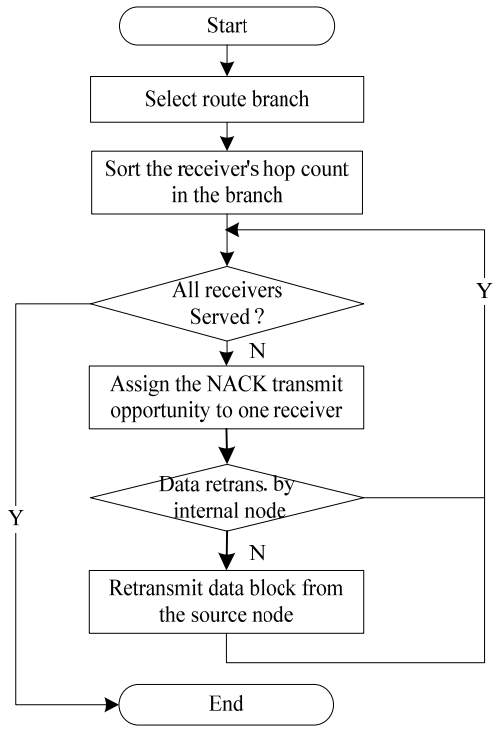

Fig. 8 Flow chart of the proposed FR-Full mechanism

The FR-Simple scheme in multicast transmission is quite similar to the unicast one. For each main branch in the routing tree originated from head end, the receiver with the farthest distance to the source node will be selected as the representing node to send out NACK message, and the other receiver will monitor the pass-by retransmission packets to check whether these packets are also missed by itself, if so, the retransmission outcome by the representing receiver can be shared.

Fig.8 illustrates the transmission opportunity assignment following FR-Full scheme in the head end for a multicast transmission. As mentioned above, the lost packet in the nearest receiver is always lost in other receivers along the transmission path, so a sorting process is done in the initial process, the request sequence is defined based on the ascending hop count from the source node. At the same time, the 1st nearest node for each receiver is also determined. The assigned receiver for NACK transmission opportunity is allowed to send request, the source node will wait one or some time slots to check whether the internal node will give response or not. If no block retransmission is detected, the source node will retransmit the required data block in the final step, then the NACK transmission opportunity moves to the next node. The iterative process will be done until all the receiving nodes have requested their lost packets.

V. SIMULATION RESULT

In this section, we use Matlab tool to do simulation and evaluate the performance of the proposed retransmission mechanism. Firstly, unicast service is investigated in the topology shown in Fig.1, two groups of packet loss combination are considered. In case one, there is severe packet loss from source node, representing the bad channel quality, and $p = 0.2, p1 = 0.05, p2 = 0.02$, here $p, p1, p2$ are the packet loss rates from the source/1st/2nd node to the destination node respectively.

Fig.9 shows the comparison of *TPHR*, it is clear to see that the proposed mechanism can achieve 99%+ *TPHR* with one time of retransmission while the traditional method needs three times of retransmission to achieve the same performance. In case two, $p = 0.1, p1 = 0.03, p2 = 0.01$, which means the channel quality is better than that in case one, the proposed mechanism still has better performance than the traditional method.

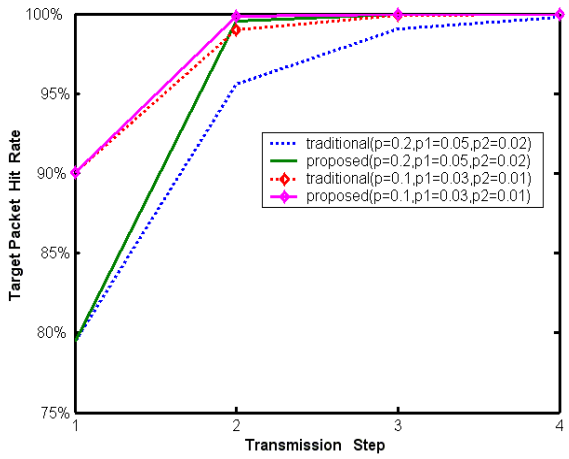

Fig. 9 Target packet hit rate comparison for unicast service

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Fig.10 shows the average transmission step under different packet loss rate from the source to destination node. The proposed mechanism has 5% – 15% improvement with respect to the step reduction. In the mean time, the amount of transmission step has direct relation with the latency generated by the interval of NACK signal message exchanging. In PLC network, the typical duration of data frame is 33ms (in North America) or 40ms (in Europe). For example, if the receiver has chance to send out ACK once every 5 frames, the average latency for retransmission data under the proposed mechanism can be less than 200ms, while the average latency under conventional method is nearly 250ms in the worst case.

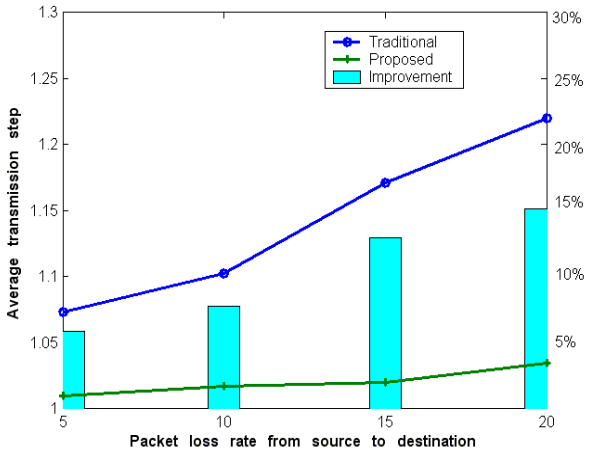


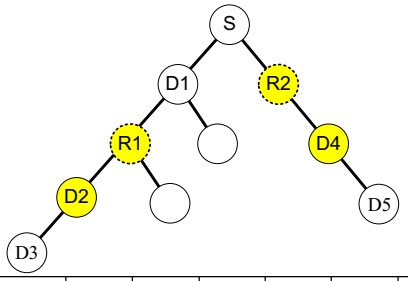
Fig. 10 Average transmission step for unicast service

We also compare the performance for the multicast service, a parameter named average packet loss rate (*APLR*) is used to compare the system improvement when the proposed retransmission mechanism is deployed. The topology for multicast service is shown in Fig.11, node with label *S* is the source node, node with label *D* (*D1~D5*) is the destination node in the same multicast session. Under the FR-simple scheme, *D3* and *D5* are selected as representing node on the left and right branch; Since *D2* and *D4* are also receiver nodes, *R1* and *R2* are regarded as the 1st node to provide assistance during retransmission. For FR-full scheduling mechanism, according to the policy for the 1st node selection mentioned in the Section III, each receiver node will be assigned its own 1st node, for example, on the left branch, the 1st node for *D3/D2/D1* is *D2/R1/S*; on the right branch, the 1st node for *D5/D4* is *D4/R2*. The packet loss rates of different peers are listed in the table.

Fig.12 shows the comparison of *APLR* for multicast service before and after retransmission. Without retransmission, the *APLR* over five destination nodes is 10.6%, after one time retransmission by R1 and R2. The *APLR* declines to 4% by FR-Simple, FR-Full scheme achieves the lowest *APLR* at 2.6%.

Fig.13 shows the comparison of unified traffic load of NACK request and cumulative retransmission traffic generated. It is clear to see that the FR-Full requires more resource to send the NACK request, but it still in possession of less NACK request than unicast retransmission method, in which each receiver requests the loss packet through a unicast connection to the sender. The advantage is obvious that more retransmission packets will be delivered and more lost packets will be recovered in the destination node. Furthermore, the duplicated packet from source node will be greatly reduced in the two proposed mechanisms.

Fig.14 compares the target hit rate in each receiver, the proposed FR-Simple and FR-full schemes can remarkably improve the performance, and the *TPHR* by FR-Full can be achieved to at least 96% for each receiver.



	D1	D2	D3	D4	D5	R1	R2
S	0.02	0.1	0.15	0.1	0.15	0.05	0.03
R1		0.02	0.06				
R2				0.02	0.08		
D2			0.05				
D4					0.05		

Fig. 11 Topology for multicast service

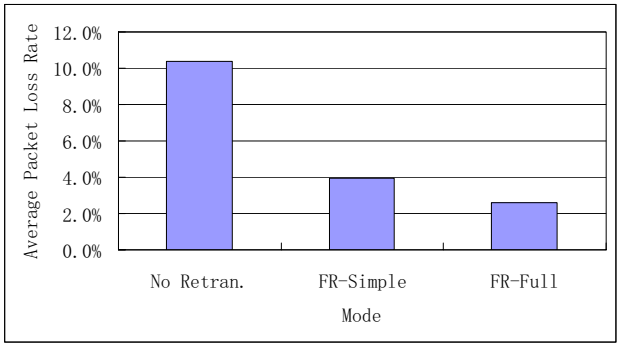


Fig. 12 Average packet loss rate for multicast service

VI. CONCLUSION

This paper presents a fast retransmission mechanism named fluctuation request which can be deployed in the indoor power line communication system. Some internal nodes in the place of transmission path contribute effort to packet retransmission. Comparing with the traditional method that totally depends on the source node to give response for the retransmission request, the proposed methods greatly improve the target packet hit rate when the channel condition between source and destination node is bad, and the retransmission step and latency will be reduced at the same time. A simple and full FR mechanism is provided for the multicast transmission to enhance the data integrity by one time or multiple retransmissions in each routing branch. Simulation results also demonstrate the improvement in target packet hit rate and the reduction of feedback request overhead.

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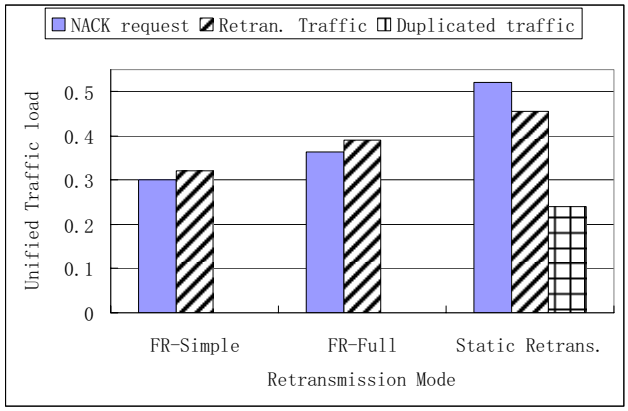

Fig. 13 Traffic load comparison for multicast service

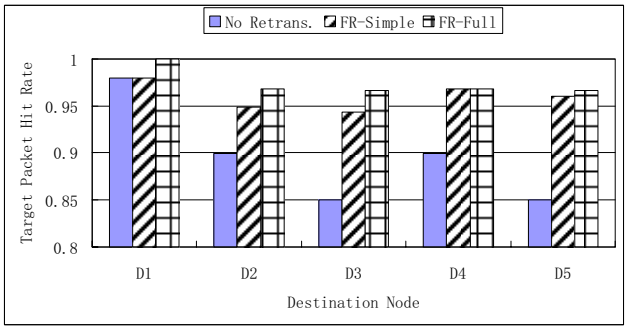

Fig. 14 Target packet hit rate comparison among destination nodes

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