Optimal segment size for transmission in multi-hop system

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***Abstract*— In this paper two schemes of the ARQ are presented: End-To-End and Multi-hop ARQ. For the second ARQ scheme the question of the additional segmentation in hops is considered.. For the Multi-hop ARQ scheme it is shown how to choose the optimal segment size in the case of limited and unlimited buffer. Also considered how the delay influences the optimal segment size.**

I. Introduction

Wireless communication and mobile communication have witnessed a fast development in recent years. Among all the other technologies in communication industry, mobile communication for its wide deployment and easy access nature has shaped our world in a profound nature. Today, more than one billion people worldwide are mobile subscribers and this number will still be increasing rapidly over the next few years. Beyond 3G or 4G mobile communication networks are designed for future needs. The major challenge of the system design in the beyond 3G mobile networks is to provide the successful multimedia service in a multi-hop scenario yet with the same level of performance as in the wired network given the intrinsic unreliability of the wireless channel and the dynamic links among the user devices, base stations and the relay nodes. Low latency and at the same time low packet error rate are required by such kind of services and many aspects in the network layers could be addressed in facing such challenges. One approach is that in the Radio Link Control (RLC) and ARQ protocol similar to the selective repeat (SR) ARQ is used. However, in the multi-hop networks, the link layer faces the different situation compared with the traditional networks where the ARQ protocol is terminated end-to-end from the transmitter to the receiver. With relaying, the ARQ protocol could either keep the same as in the traditional approach that bypasses the relay node or terminate at the relay node and set up another link from the relay node to the receiver in a two hop scenario. These two schemes are called End-To-End ARQ and Multi-hop ARQ, accordingly. According to the previous work [1], one scheme is chosen and further this paper describes the situation, when the channel throughput at these hopes is not the same, so the question of additional resegmentation is discussed. For simplicity, the choice of the segment size only for one hope is described in this paper in details. This paper is organized as follows. Section II describes the Relay Nodes (RN) in the future mobile communication systems. Section III discusses two RLC layer schemes. Section IV presents the system description and problem statement. Section V focuses on the resegmentation problem and optimal packet length for single hop case. Section VI presents the results for the case with two hops.

II. Cellular network with Relay

Relay is one of the key concepts and technologies in the scope of 4G system, it allows for flexible deployment and cost efficient solutions. There are different relay node concepts such as fixed relay nodes and mobile relay nodes. The concept of relaying comes from the multi-hop mobile communication system where originally mobile device relies on the other mobile devices for relayed communication between the mobile nodes rather than the base station. However, the mobile devices relying on the other device for relaying depend on the probability that there are other devices nearby. Some researches are dedicated to cooperate relaying between the different relay nodes in order to mitigate and make use of the multipath effect in the wireless channel [2] and [3]. In [4] the enhancement brought by the fixed relay nodes to the system coverage and capacity in addition to the mobile relay nodes is discussed. From the User Terminal (UT) side , the RN has not much difference compared with the Basic Station (BS).

Along with the increasing throughput demanding of the data service, mobile communication system has to provide higher capacity and larger coverage. However, the properties of radio wave propagation set limitation to the radio coverage [5]. The classical deployment of the cellular system encounter challenges to meet the service demand. Thanks to the introduction of relay nodes in the cellular system, fast degradation problems caused by distance from the receiver and transmitter can be reduced.

The following characteristics are contributed by cellular relay entities:

1) Significant reduction of signal attenuation

2) Data transmitted between BS and the UT is stored and forwarded later on the next transmit opportunity, therefore the relay helps the adaptation of the transmission formats in each segment of the whole transmission chain. That provides more diversity gain and high throughput at each segment

3) Relay station is designed as low-cost low transmit power devices compared to BS

4) The radio network is flexible to choose fixed relays or mobile relays. In the fixed relay case, the topology is like a tree structure, which resolves the routing complexity. In the mobile

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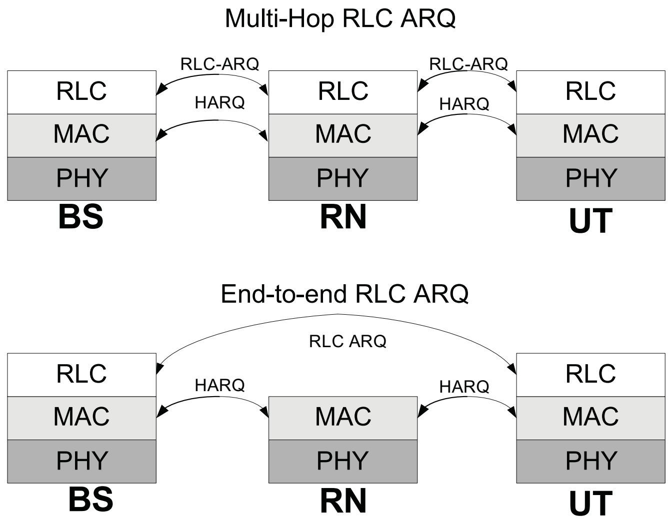

Fig. 1. Two RLC layer schemes in REC

relay scenario, number of relays involved in the transmission path is flexible

5) Simultaneous transmissions of BS and RN, or only among RN, with the same data or different data are possible, so that flexible diversity mode and spatial multiplexing can be achieved with additional system capacity gains

Among the number of multihop modes, two of them could be marked out. These are amplify and forward and store and forward. The second mode breaks out into submeodes: woth and without decoding. At the same time we can transmit immediately or with schedule. In the paper we restrict ourselves to the second mode with decoding. In the case of the successful decoding we transmit further, in the case of unsuccessful decoding - request to repeat.

III. Two kinds of RLC layer schemes

There are two kinds of RLC layer schemes in the relay enhanced mobile communication networks as shown in Figure 1.

The asymmetry among two hops in a multi-hop network degrades the efficiency of the traditional end-to-end RLC layer protocol, since even if only one hop among all the hops experiences worst channel condition, the effect will be propagated to the final hop. For example, in a downlink two hop scenario in the B3G networks, the first hop is the link between BS and RN which is a pointed beam in most case, thus the SINR is really high and the MAC will hardly have failure delivery of MAC PDUs within its maximum retransmission limit. While on the second link between the RN and UT, the UT may move really fast or experience a deep fade, both of which lead to a poor SINR value and hence the probability of MAC failure is much higher than that on the first hop. If there is no RLC layer protocol on the RN, the RLC layer on the UT finds out that some PDUs are missing, it has to send a status report to the BS that is two hop away and wait for the retransmission from the BS. Those retransmitted PDUs also have to travel along two hops in order to be received by the UT. If the RN has RLC entity on its own, the situation would be different that the UT only has to send status report to RN and asks for the retransmission from RN. Both the status reports and retransmission PDUs travel only one hop from the UT to the RN. Based on the observation above, two kinds of RLC layer schemes in the relay enhanced mobile communication networks were investigated. The first scheme is called ”Multi-hop RLC ARQ” scheme which has the RLC receiver and sender entity on the RN. In this scheme, both the BS-RN link and the RN-UT link have their own radio link control layer. The second scheme is called ”End-to-End RLC ARQ” scheme which only has RLC entity on the BS and UT. According to the previous results (see [1]), it can be noted that the scheme ”Multi-hop RLC ARQ” performs better. Based on this, in future investigation only this scheme will be taking into account.

IV. System description and problem statement

Let us consider the multi-hop RLC ARQ scheme. To solve the problem of the optimal message segmentation while sending messages from base station to relay node and from relay node to user terminal, it is necessary to be able to solve this problem at least for the way from relay node to user terminal. For solving this task consider several assumptions.

1) Base station has continuous sequence of messages of k information bits that could be divided into segments.

2) Transmitter sends data with the check sum consisted of r bits. It is possible to find errors in the message due to this check sum. It is also considered that all errors could be recognized.

3) Receiver send the positive acknowledgement if the message is received successfully and negative acknowledgement if errors occur. It is important to notice that there are no errors in the reverse channel.

4) Transmitter receives acknowledgement after constant period of time τ after sending the message. In this paper this delay will be counted in the times of sending one packet.

5) In the forward channel errors occur with the probability P for one bit of the transmitted message. The probability that an error occurred but was not found equals zero (see assumption 2)

6) All the events connected with error appearance are considered to be independent.

We will consider the case of packets transmission using this set of assumptions and answer the question of packets additional segmentation and the optimal packet size.

V. Single hop case

Relay node is used for transmitting big amount of packets from lots of users. Therefore, there is a constraint for the buffer size. The throughput depends on the following values:

- Bit error probability
- Packet size
- Number of segments in the packet
- Length of check sum

- Delay
- Type of used algorithm and number of segments that could be stored on the receiver side and buffer size.

According to the characteristic number three in the second section that RN is designed as low-cost low transmit power devices compared to BS the buffer size should be limited. However, it does not mean that the packets would be dropped out when the buffer is overfilled. In this case RN send this information to the BS and BS does not send packets until the buffer has some space.

The minimal size of the buffer with that system can function equals one packet. It is necessary to underline that although we transmit the packet with the check sum, there is no need to store this check sum at the receiver side. If Go Back N algorithm is used for packet transmission then no segments are stored at the receiver side. If selective repeat algorithm is use then several segments are stored at the receiver side. In general the formula for channel throughput is following[6]:

$$\eta = AB, \tag{1}$$

where A does not depend on the ARQ algorithm, B - depends on the particular qualities of the ARQ algorithm. ($1/B$ can be interpreted as the average transmission number of one segment).

For all cases this formula is calculated in two steps. The first multiplier is the following:

$$A = \frac{k/N}{k/N + r}, \tag{2}$$

where k - length of the initial packet, N - number of segments in the packet, r - length of the check sum.

Second multiplier takes into account the particular qualities of the ARQ algorithm. The calculation of the delay value y (computed in the number of segments) and probability of the segment error is following:

$$y = \left\lceil \frac{\tau(k+r)}{k/N + r} \right\rceil, \tag{3}$$

$$q = 1 - (1-P)^{k/N+r}, \tag{4}$$

where τ - delay value in the channel in the number of packets (see assumption 4), k - length of the initial packet, N - number of segments in the packet, r - length of the check sum, P - probability of the bit error.

For computing the value of probability of segment error we take an assumption that the probability of bit error does not depend on the segment size.

For Go Back N algorithm second multiplier equals

$$B = \frac{1-q}{1+yq}. \tag{5}$$

For selective repeat algorithm when we store one segment at the receiver side the second multiplier is computed as following [7]:

$$B = \frac{1}{1 + \frac{q(y+1)(1+q)}{1+q-2q^2}}. \tag{6}$$

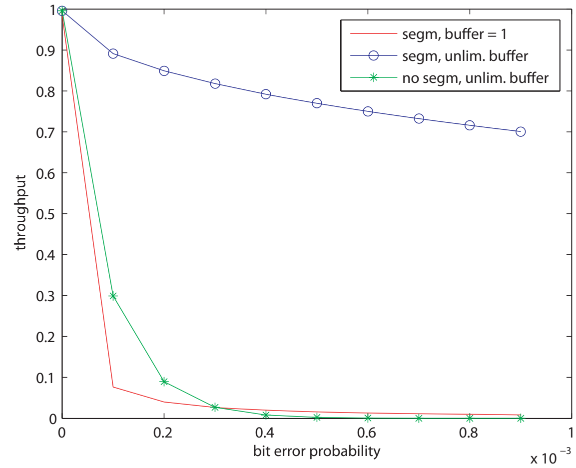

Fig. 2. Different ARQ schemes comparison(high probabilities)

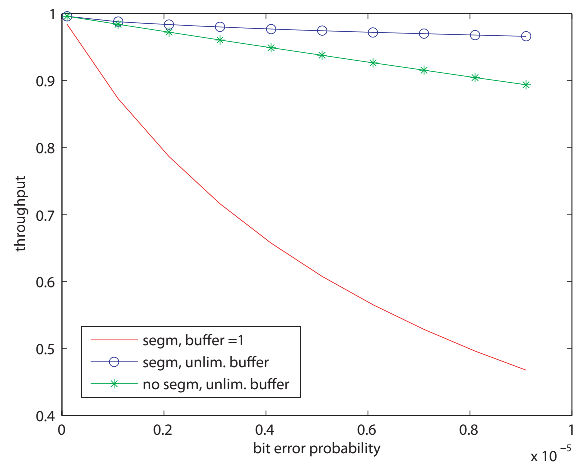

Fig. 3. Different ARQ schemes comparison(small probabilities)

If there is no buffer constraint at the receiver side the following formula is used:

$$B = (1-q). \tag{7}$$

For Go Back N algorithm and selective repeat with infinite buffer formulas (5) and (7) accordingly can be found in many papers, for example [6].

For selective repeat algorithm when more than one segment is stored at the receiver side this multiplier could be approximately calculated or estimated by the simulation.

These computations were made based on the assumption that bit error probability does not depend on the segment size. In practice, bit probability error decrease with the increase of the segment size. However, even without this feature the computations show that there is no need for additional segmentation on the relay node when there is buffer constraint.

These graphs (Figure 2 and Figure 3) were built with the following parameters (see Table 1).

Consider three cases.

TABLE I

TABLE1

Packet length	1500 bytes
Probability bit error	from 0,001 to 0,00001
Length of check sum	4 byte
Buffer size	1500 bytes or infinite

1) There is a buffer only for one packet, and segmentation is used. There is a choice from two algorithms: Go Back N (calculation with formula (5)) and selective repeat with buffer for one segment (calculation with formula (6)). The algorithm with the best throughput is chosen. This case is called "segm, buffer = 1".

2) There is infinite buffer on the receiver side. The selective repeat algorithm is used and the optimal segment size is chosen. On the graph this case is called "segm, unlim. buffer".

3) The same situation as in the previous case with the only difference that there is no segmentation at all. This case is called "no segm, unlim. buffer".

It is necessary to underline that there are no graphs for the intermediate cases when selective repeat algorithm is used and it is possible to store more than one segment on the receiver side. It is clear from the Figure 2 that for high probability values there is a small gain of the algorithm with limited buffer with segmentation when either the Go Back N algorithm is used or selective repeat algorithm. Figure 3 shows that in the case of limited buffer on the receiver side segmentation is not needed and with the increase of the probability the difference becomes significant. So, the segmentation is needed only for high error probability value or in case of the unlimited buffer.

VI. Two hops case

Consider the case of the selective repeat algorithm with infinite buffer on the relay. Consider the same assumptions as in section IV. Data is transmitted from BS through RN to UT. It is also considered that successfully received packets on the UT are immediately sent to the upper layers.

The model is presented on the Figure 4. Let P_1 be the probability bit error on the hop from BS to Relay, and P_2 - probability bit error on the hop from Relay to UT. With the above-mentioned assumptions for transmitting one segment on the first and second hops accordingly we need

$$T_{servise1} = \frac{1}{1-(1-P_1)^{\frac{k}{n}+r}}. \tag{8}$$

and

$$T_{servise2} = \frac{1}{1-(1-P_2)^{\frac{k}{n}+r}}. \tag{9}$$

time slots. One time slot is the time of transmitting one segment.

Consider two cases.

1) Let $SNR_1 < SNR_2$, therefore $P_1 > P_2$, then $\overline{T}_{service1} > \overline{T}_{service2}$. The work of the RN can be presented as the queuing system with one server with service time

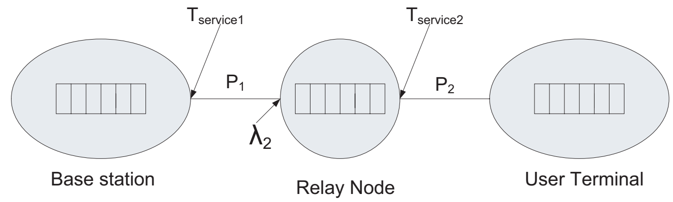

Fig. 4. The scheme of data transmission in the channel with relay node

$T_{service2}$ with the arrival rate of

$$\lambda_2 = \frac{1}{T_{service1}}. \tag{10}$$

Then following inequality holds true

$$\lambda_2 \cdot T_{service2} = \frac{T_{service2}}{T_{service1}} < 1. \tag{11}$$

If $P_1 > P_2$, then for any length of the segment on the relay node will be finite queue, so we can choose the segment length so that optimize the throughput on the first hop.

2) Let $SNR_1 > SNR_2$, therefore $P_1 < P_2$, then $\overline{T}_{service1} < \overline{T}_{service2}$.

$$\lambda_2 \cdot T_{service2} = \frac{T_{service2}}{T_{service1}} > 1, \tag{12}$$

therefore the system will work unstable and the queue will be overfilled. So the relay has to send negative acknowledgement and the work of the system will be defined by the worst hop.

So the optimal number of segments will be chosen as following:

$$\frac{k/n}{k/n+r}(1-\max(P_1,P_2))^{k/n+r}. \tag{13}$$

The optimal value of n will be the value that maximize the above-stated formula. If we modify the assumption 1 in the following way: from the upper layer the continuous sequence of l bits is received. In this case the throughput will be computed with the following formula

$$\frac{l}{l+r}(1-\max(P_1,P_2))^{l+r}. \tag{14}$$

The optimal size of the segment will be the value of l that maximize the above-stated expression.

If from the upper layer come the continuous sequence of the messages (see assumption 1) or the continuous number of bits (see modified assumption 1) then the optimal segment size is determined by the part of the channel with the worst throughput and computed with the formulas 1 and 2 accordingly. In this case there is no need for additional resegmentation.

For the above-mentioned case with the infinite buffer, the delay does not influence the throughput for the selective repeat algorithm. Let us now generalize these arguments for the case of limited buffer. Let RN and UT have limited buffer. Go Back N algorithm is used for the transmission. The delay between the moment of the end of message transmission by BS and the moment of receiving the acknowledgment from RN equals τ_1 (i.e. it is possible to transmit τ_1 packets during this

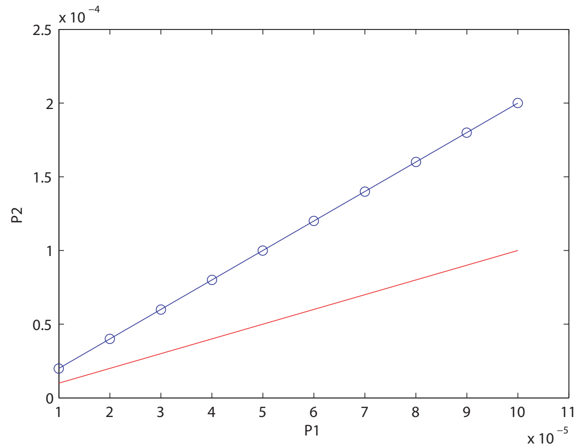

Fig. 5. $\tau_1 = 2\tau_2$

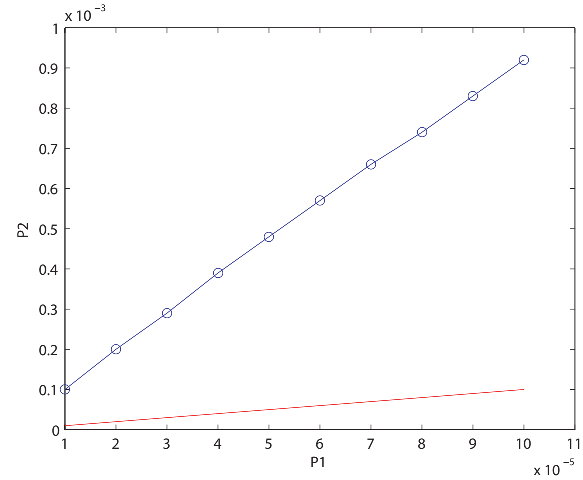

Fig. 6. $\tau_1 = 10\tau_2$

period of time). The delay between the moment of the end of message transmission by RN and the moment of receiving the acknowledgment from UT equals τ_2. For simplicity we limit our discussion to the case when SNR on the hop between BS and RN is bigger than between RN and UT, (i.e. $P_1 < P_2$).

Taking into account all assumptions the time from message sending on the first hop equals

$$T_{service1} = \frac{1 + y_1 q_1}{1 - q_1} \tag{15}$$

, and on the second

$$T_{service2} = \frac{1 + y_2 q_2}{1 - q_2}. \tag{16}$$

Let us repeat the discussions based on the relay node as the queuing system. Consider two cases.

1)If $\tau_1 < \tau_2$, then everything is determined by the worst throughput, as in this case $T_1 > T_2$.

2)If $\tau_1 > \tau_2$, then for some values T_1 can be more than T_2. Therefore, we should choose the segment size based on the channel with the higher SNR level.

Let us find out the values of P_1, P_2, τ_1, τ_2 when this could be possible.

Consider the following graphs(Figure 5 and Figure 6). The lower line corresponds to the case of the infinite buffer. The area under it is not interesting for us as we defined that $P_1 < P_2$. The area between these two lines corresponds to the situation when the optimal segment size is determined by the first hop. The more the difference between τ_1 and τ_2, the bigger this area is. The area higher than line with circles is the area where optimal segment size is determined by second hop.

The discussion stated above could be generalized for the case when UT and RN have the unlimited buffer and the selective repeat algorithm. In fact, two extreme cases are considered. In the case of the infinite buffer the area when the segment size will be determined by the hop with the highest SNR is absent. With the buffer limiting this area extends and the border of this area is the line that corresponds to the above-mentioned case of Go Back N algorithms. It is possible to determine such an area by combining numerical computations and simulation for the buffer of finite size.

VII. Conclusion

For the channels with high SNR (probability bit error less than 0,001) with the relay buffer of minimal size message resegmentation does not give a big throughput gain. If there are no limitations on the buffer size then message segmentation is needed and it is easy to find the optimal segment size. For the case of two hops and unlimited buffer the segment size is determined by the worst SNR. If the buffer is limited, delay in channel will also influence the optimal segment size. And for some cases when the delay in the hop with higher SNR is more than delay in the hop with smaller SNR the optimal segment size will be chosen according to the channel with higher SNR. For the case of Go Back N algorithm and buffer of minimal size the method of choosing optimal segment size and the area where it is possible is shown. All the cases in the paper were considered on the assumption of situation when probability bit error does not depend on the segment size.

So, the paper considers the case that we have a continuous sequence of packets or bits, and it was needed to maximize the throughput. For solving this task it was unnecessary to make resegmentation. If we have a sequence of packets that appears through random time intervals, that is a task of the minimization delay in packets delivery. For solving this task it could be needed to make resegmentation on RN. To make this resegmentation or not - it follows from the statistical properties of the sequence. For example, if we have had to transmit only one packet and minimize the delay for one packet , it would be good to make a resegmentation. At first we have had to choose the optimal size for the first hop, and then for the second hop.

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