International Conference on Advanced Communications Technology(ICACT)

Performance Evaluation: Two Flood-Cancellation Methods of the Blocking Expanding Ring Searches on the AODV/WiFi MANET Environment

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Abstract—**Blocking Expanding Ring Search(BERS) is the modified scheme of TTL-sequence based ERS(TTL-ERS) to increase the energy efficiency by adding a little latency and decreasing the number of route request packet(RREQ)s which are flooded into network to query the path during the route discovery process for the reactive routing protocol of Mobile Ad-hoc Network (MANET). Until recently, several variants of BERS have been proposed, and all of them use 'chase' packet to stop or cancel the flooding of the RREQ for fulfilled route request. In this paper, we modelled these main variants of BERS, classifying them into Source node Initiated Chase Packet (SICP) type and Reply node Initiated Chase Packet (RICP) type, and analyzed the performance of each scheme installed in AODV protocol over WiFi MANET environment by the NS-3 simulator. The results of this paper show undiscovered aspect, different from the results of mathematical and analytical studies or the results of network simulation performed on the low node density network: the performance value of the BERS series deteriorates dramatically after node density of the network comes high. It means that broadcasting of chase packet as well as broadcasting of RREQ is a large burden on the dense node WiFi network. Notably, this phenomenon is more distinct in the SICP type model (BERS, BERS*, BERS+), and it even leads to greater overhead than TTL-ERS in case of very high node density network. On the other hand, the RICP type models (tBERS, tBERS*, tBERS+), which are improved to start flooding cancellation earlier than SICP, exhibit greater performance improvement than expected in case of higher node density. These results show that, in the BERS series models, flooding cancellation by the broadcasting packet can be another factor of the broadcasting storm, and that the earlier the flooding cancellation, the greater the performance improvement effect than theoretical prediction in the high node density WiFi MANET.**

Keywords—**Blocking Expanding Ring Search(BERS), Broadcast storm, Flood Cancellation, MANET, Reply node Initiated Chase Packet(RICP), RREQ, Source node Initiated Chase Packet(SICP)**

I. INTRODUCTION

Mobile Ad hoc Network (MANET) is defined as "distributed, mobile, wireless, multi-hop networks without the benefit of any existing infrastructure except for the nodes themselves."[1]. It has self-organizing, adaptive and cooperative characters [2].

AODV (Ad hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing), popular reactive routing protocols for MANET, adopt Expanding Ring Search (ERS) to prevent broadcast storms, to lower the routing overhead or to save energy consumption during the "Path Discovery" process, where a source node floods Route REQuest(RREQ) packets to probe the path information to the destination [7][8].

Although the ERS, one of the controlled flooding methods, is a much better technique than blind flooding, it is still limited to solve all the problems. ERS is the process where a source node repeatedly floods RREQ packets with a sequential increment of TTL value until it receives the Route REPly (RREP) packet from the route node (intermediate nodes which have a path to the destination or a destination node itself, called as reply node in this paper). Therefore, there exists a significant packet redundancy, still with a lot of energy consumption. Moreover, the cost of the ERS relatively more increases when it should search for the path within a larger area of the network [3][4][5][6].

To reduce that problem, new ERS called "Blocking ERS (BERS), based on original ERS(TTL-sequence based ERS, for shot TTL-ERS), with improved energy consumption but with a little latency added, is suggested for the first time by the authors of [9]. In BERS, intermediate nodes, instead of the source node which started Path discovery, can take charge of packet flooding to next ring after certain delays (called blocking time, waiting time or holding time) [9][10].

BERS has been a new challenge to ERS researchers. So they could propose various new models improved from the BERS, such as BERS-Star (BERS*)[4][5], BERS-PLUS (BERS+) [6][11], Time-efficient BERS(tBERS), tBERS* [5], Broadcast Cancellation Initiated on Resource (BCIR), BCIR*[12], Improved-BERS (I-BERS) [13].

However, a significant portion of recent researches about the variants of BERS (We call them as B-Series ERS or BERS series in this paper) has been conducted only with mathematical approaches and analytical simulations [4][5][9][12]. Thus, they have not been considering the nature of WiFi network on which the actual MANET can be deployed actively. When we practically apply the conditions of the WiFi network, such as loss/delay of radio propagation, channel contention, hidden/exposed terminal, error models of

MCS, network congestion and etc., we could figure out a result different from that of previous studies.

Although there were some studies on BERS series, conducted over the WiFi condition through the network simulator, those simulation studies do not adequately reflect various condition and environment of MANET. For example, [6] and [11] were conducted in an environment of very low node density, 0.8 to 4.0(when calculated according to [14]), or 0.63 to 3.2 with maximum neighbour nodes 2.2 (assumed by data of [1] or [15]), which is definitely lower considering the realistic condition, for the studies of [1][15] [16][17] declared that MANET performance is optimal when the average number of neighbors is between 6~8.

Reference [13] also simulated over the WiFi, but it did not directly note the node density and the number of data sessions. Moreover, this simulation is conducted in a low-speed range (0.5~2.0 m/sec) of mobility, in spite of that MANET routing overhead is not significantly affected in the speed over 5 m/sec by the result of [1]. So, it is a vague result and limited simulation to the reader. Therefore, it is needed to provide extended simulation models over WiFi network having optimal node density or above, with wide mobility level range, to evaluate the performances of B-Series schemes in general and objective condition of the MANET.

Our study was conducted with NS-3 simulator on WiFi network with AODV protocol, into which we applied various requirements previously mentioned. Realistic wireless channels and MAC condition are provided by WiFi network of NS-3, and the simulation was executed within the extensive range of node density from low to high (2.2~17.18) including the optimal density of MANET as a median value of the range. Therefore, this study regards relatively dense network than previous studies, along with low node density, too.

In this paper, we classify the BERS series schemes into Source node Initiated Chase-Packet (SICP or Source node Initiated flooding Cancellation Packet) type and Reply node Initiated Chase Packet (RICP or Reply node Initiated flooding Cancellation Packet) type as previous studies did with other names. We not only compare each B-Series scheme with the others but also mainly analyze the difference between these two types of models.

As a result, the new aspect which was not revealed by previous studies is suggested. That is, the performance value of BERS series model appears to be outstanding at low node density as it is known, but it goes rapidly lower as the node density goes higher than medium density. So the SICP type models show bigger overhead than TTL-ERS model at high node density. From this result, our paper suggests that Chase packet, disseminated to cancel the RREQ flooding, rather can be another cause of congestion or broadcast storm in the high-density WiFi network. Meanwhile, RICP models improved from SICP models have similar problems, but their performance decline starts at even higher node density, and it shows much greater improvement of performance than numerical expectations of other researches.

In the rest of the paper, we present related works briefly in section 2. And then describe the simulation environment, performance metric, and simulation methods in section 3. Section 4 shows the main simulation results, analysis and discussion. Finally, we summarize and conclude our study in section 5.

II. RELATED WORKS

According to the classification of survey paper [3], the control methods of all the B-series ERS and TTL-ERS are “bounded broadcasting technique,” one of the “controlled flooding” methods, which bounds the route query packet(RREQ) to stop when it reaches certain hop to prevent unnecessary circulation of them.

A. TTL- Sequence based ERS

The TTL-ERS model is adopted as a standard in AODV routing protocol, and the detailed parameters of which are shown in [7]. The TTL-ERS scheme has been researched for many years, so most of the B-Series ERS study paper includes the algorithm of it [3]-[6][10][11]. So we are not going to describe it in detail here.

Using TTL-ERS has an advantage of avoiding congestion by reducing the number of RREQ packet, in comparison with blind flooding. However, there still exist many problems such as increased delay of path discovery process, redundancy of RREQ packet and routing overhead, due to the repeating process of the source node, and too higher cost in case of searching a larger area [4][5][6][9].

B. SICP type Blocking ERS

In the Source node Initiated Chase Packet(SICP) type models, the source node takes the role of initiating Chase packet as explained in Fig. 1. B-Series ERS such as BERS, BERS-Star(BERS*), BERS-PLUS (BERS+) can be classified as this SICP type model.

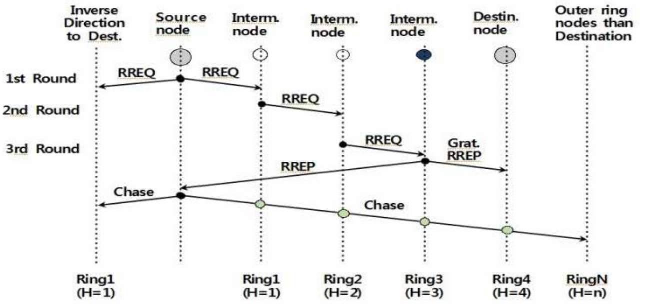


Figure 1. The concept of SICP(Souce node Initiated Chase Packet) type models such as BERS, BERS*, BERS+.

1) Blocking ERS (BERS) : Blocking ERS is the modified algorithm of TTL-ERS scheme suggested by the authors of [9] for the first time. BERS brings two unique methods to reduce RREQ retransmission which is related to the reduction of energy consumption.

First, instead of sending RREQ from the source node on and on for the second or subsequent round to expand search ring, the intermediate nodes which received the RREQ packet waits a predefined time and broadcasts the RREQ packet to the next ring by itself to continue the ERS function as depicted in Fig. 1. Here the Waiting Time of the intermediate node is "2 × hop × Node Traversal Time (NTT)".

Second, after receiving Route Reply(RREP) packet from the intermediate node or destination node itself (both of them can be a reply node), the source node broadcasts Chase packet again into the network to stop the flooding of the RREQ packet. It prevents the fulfilled RREQ packet from flooding outside of the reply node's ring. Here, the Chase packet can only be delivered to the ring number of reply node.

The authors of [10] declared that BERS reduces the energy consumption, i.e. the number of RREQ packets, instead of taking a little more latency in proportional to the hop count between source and destination than TTL-ERS.

***2) Blocking ERS Star (BERS*)*:** The paper [4] introduced the BERS* model that further improves the time latency by reducing the wait time of the intermediate node to half compared with BERS. But more RREQ packets are generated than BERS by this modification, because RREQs could go one more hop than BERS before the Chase packet stops them.

***3) Blocking ERS Plus (BERS*+)*:** BERS+ method, introduced in [6] and [11], has only one difference from original BERS: discarding position of the Chase packet. Whereas the discarding point of Chase packet in BERS scheme is limited to the ring number of reply node, in BERS+, it is extended to the end of network diameter. By this, Chase packet can find and cancel the RREQ packet without being abandoned even outside of reply node's ring.

C. RICP type Blocking ERS

The difference between SICP type and Reply node Initiated Chase Packet(RICP) type is the node which initiates the Chase packet. In contrast to the former one, the reply node takes the role of initiating the Chase packet in RICP type model, as depicted in Fig. 2.

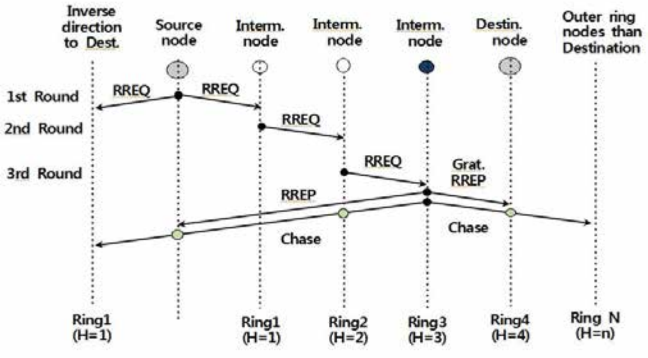


Figure 2. The concept of RICP(Reply node Initiated Chase Packet) type models such as tBERS, tBERS*, tBERS+.

So the RICP type models start flood cancellation earlier as amount as "hop count between Source and Reply node × NTT" than SICP type models [5][12].

***1) Time Efficient BERS (tBERS*)*:** As proposed in [5], in the tBERS scheme, Reply node initiates the Chase packet rather than Source node immediately after sending RREP.

***2) Time Efficient BERS Star (tBERS*)*:** The tBERS* reduces the waiting time of each intermediate node into half than tBERS'. And Reply node initiates the Chase packet after it transmits RREP back [5].

3) BCIR, BCIR : Broadcast Cancellation Initiated on Resource (BCIR) and BCIR* introduced in [12] have basically the same concept as tBERS and tBERS* respectively.

The authors of [5] provided the table that compares five models on energy consumption and route discovery latency, as attached below.

TABLE 1. ENERGY CONSUMPTION AND ROUTE DISCOVERY LATENCY (TAKEN FROM [5])

Scheme	Energy Consumption	Latency
TTL-ERS	$(N_r+1)H_r+\sum_{i=1}^{H_r-1}\sum_{j=1}^{i} n_j$	$H_r+H_r^2$
BERS	$2(1+\sum_{i=1}^{H_r-1} n_i)+N_rH_r$	$2H_r+H_r^2$
tBERS	$2(1+\sum_{i=1}^{H_r-1} n_i)+N_r H_r$	$H_r+H_r^2$
BERS*	$E_{BERS}+2n_{H_r}-N_r$	$1+2.5H_r+0.5H_r^2$
tBERS*	$\leq E_{BERS}+2n_{H_r}-N_r$	$1+1.5H_r+0.5H_r^2$

* *In the table, n_i and n_j mean the number of broadcasting nodes in ring i and j, where i and j = 1,2,…, H_r. H_r represents the hop number of route node (i.e., reply node) and N_r is the number of route nodes on the ring H_r*

With the mathematical study and analytical simulation, [5] concludes that the latency order of the models is "tBERS* < BERS* < tBERS = TTL-ERS < BERS." Besides, the energy consumption order is " tBERS = BERS < tBERS* < BERS* < TTL-ERS" at the hop 10. This analytical result, i.e. performance order, could be changed if the variety of realistic wireless network conditions is fully considered.

***4) Time Efficient BERS Plus (tBERS*+)**: This model has not been proposed concretely by the authors of BERS+[6][11]. However, it can be inferred easily though they did not describe it in detail. We modelled tBERS+ by applying the concepts of RICP to BERS+ to review its performance over the WiFi network.

III. SIMULATION ENVIRONMENT, METRICS AND SIMULATION METHODS

This study used the NS-3 simulator ver. 3.26 to evaluate the performance of B-Series ERS models including TTL-ERS over WiFi based MANET. For these experiments, we modified the AODV protocol module sources and the sample routing compare program of NS-3[19][20] to apply 3 SICP type models (BERS, BERS*, BERS+) and 3 RICP type models (tBERS, tBERS*, tBERS+) in the AODV protocol. NS-3's WiFi module and Channel module are used for WiFi MANET environment.

A. Simulation Environment

The paper [14] suggested important guidance and metrics for MANET simulation design to get the accurate and unbiased performance assessment. Our study tried to follow that guidance and assigned the simulation parameter related to major “design spaces” of [14] as listed in Table 2.

TABLE 2. SIMULATION PARAMETERS

Parameters	Values
Topology Map size	1500 m × 1500 m
Transmission Range	250m (Tx Power 10.65 dBm; Energy Detection Threshold -82.0 dBm)
Mobility Model	Random way-point
Maximum node speed	20 m/sec; 3~21(increased by 6)
Pause time	0 sec
Total number of node	20 ~ 160 (increased by 20)
Propagation Delay Model	Constant Speed Propagation Delay Model
Propagation Loss Model	Friis Propagation Loss Model
PHY model	YANS WiFi, DSSS Error Model
MAC model	IEEE 802.11b (2Mbps) with RTS/CTS, DCF
Remote Station Manager	Constant Rate WiFi Manager
Number of Concurrent Data sessions	10 ~ 40 (increased by 5)
Data Traffic	UDP, CBR, 512Byte, 16kbps (4packet/sec) / session
Simulation Time	600 sec (Initial idle moving, 100 sec)
Number of Run	20 (with different seed numbers)

The benchmark paper [14] emphasized the importance of node density to understand the dynamic characteristics of MANET and it proposed a formula for coarse calculation of average node density, i.e., the Number of Nodes per cell with assuming of Grid distribution of nodes (Node Density in Grid, - NDG in our paper) from the size of topology map, as follows. In here, Tr is Transmission Range.

- *the number of cells = (width*height) / (2* Tr)^2* (1)
- *NDG = the number of nodes / the number of cells* (2)

The node density directly affects to the average Number of Neighboring Node(NNN, in our paper) naturally, and the study [1][15]-[17] declared that MANET performance is optimal when the average number of neighbors is between 6~8. We could calculate the assumed NNN value from NDG value as like Table 3, in which the obtained NNN value is similar to the measured value of it in the [1][15].

Our study varies the number of the node from 20 to 160 nodes within the square area of 1500m * 1500m, and corresponding node density is calculated in Table 3. Our simulation results display that the node count of the optimal network was 80 to 100, at which the NNN is 5.9 to 7.7. It almost matches the optimal condition of neighboring node count, 6 to 8, explored in the previous study of [1][15]-[17].

TABLE 3. NODE DENSITY CALCULATED FROM TOPOLOGY MAP

Nodes	20	40	60	80	100	120	140	*160*
NDG	2.2	4.4	6.6	8.8	11.11	13.33	15.56	17.78
NDC	1.73	3.46	5.18	6.9	8.7	10.5	12.2	14.0
NNN	0.73	2.46	4.18	5.9	7.7	9.5	11.2	13.0

*NDG: average Node Density in Grid (=node count / cell count)
NDC: average Node Density in Circle (≈NDG*0.7854)
NNN: average Number of Neighboring Nodes(≈NDC-1, naturally)

B. Performance Metrics

In this study, we select well known, general performance metrics for comparison of each scheme.

***1) Routing Overhead 1 (The Number of RREQ and Chase Packets)* :** Many studies on BERS series consider the number of control packets as a factor of not only routing overhead but also energy consumption [4][5][6][9]-[12]. In particular, the number of “RREQ + Chase” packets was used as a representative metric which reflecting dynamic characteristics of BERS series in [6][11]. Our study also follows that concept. The number of other control packets including RREP is considered in the below metric.

***2) Routing Overhead 2 (Routing Overhead Ratio)*:** It is the ratio of the total byte of all routing control packets including RREQ, RREP, RERR(Route ERRor), RCHASE (except Hello packet) required to maintain routing path, divided by the total received user data byte. It means that how many times bytes are transmitted for routing control compared to the byte of user data. The result graph pattern of routing overhead 1 and 2 are similar, so this metric is only mentioned if necessary.

***3) End to End* Delay:** The average time taken for user data packets to be transmitted across a network from the source node to the destination node. It includes route discovery latency**.**

***4) Packet Delivery Ratio*:** The ratio of the number of user data packets received in the destination divided by the number of user data packets sent from the source. The unit of it is %, and the loss rate is "1 – packet delivery rate".

***5) Network Throughput*:** The total number of user data bytes sent, divided by the total time for sending/receiving those data. In this paper, the data rate of each node is 16 kbps. So the maximum data rate of the network can be the value of "the number of source nodes × 16kbps." Throughput shows almost the same pattern of packet delivery rate as long as there is no change in data session or in traffic volume, so this metric is only mentioned if necessary.

C. Simulation Methods

The Simulation of every model was tried 20 times with different seed numbers. Each simulation time is 600 seconds. The first 100 seconds are the time for free transfer of the nodes so that they can be uniformly distributed, and the data transmission occurs during the rest 500 seconds.

For the fairness, all BERS series models and TTL-ERS model have the same Path Discovery Time(PDT) limit, and the TTL-thresholds of each model are tuned to transmit the RREQs to the last ring within the same PDT.

So, if the hop number of RREQ exceeds the TTL-threshold at the intermediate node, the node broadcasts the RREQ without waiting time into the whole network. Also, Chase packet does not chase the RREQ packet if the hop number of reply node exceeds this threshold for the better performance.

The simulations were conducted with three main variables. First, we measured the performance metrics for node count variation increasing from 20 to 160 by 20 nodes scale of change, with the fixed data session, 10 and with fixed mobility, 20m/sec. The number of nodes can be converted into node density as represented in Table 3.

Second, we measured the performance metrics for the data session count variation from 10 to 40 sessions by five session scale of change, with the fixed node numbers, 100, and with fixed mobility, 20m/sec

Third, we varied the mobility level from 3m/sec to 21 m/sec by a 3m/sec scale of change, with the setting of the number of nodes as 100, data sessions as 25.

IV. RESULTS, ANALYSIS AND DISCUSSION

A. *For the node density variation*

1) The number of RREQ and Chase packets (control packets) representing power consumption or overhead : Fig. 3 mainly illustrates the control packet count which is the sum of the number of RREQ and Chase packets, varied by the node count. The graph shows some important new aspects which have not been presented in other BERS researches so far. We will explain these in three ways.

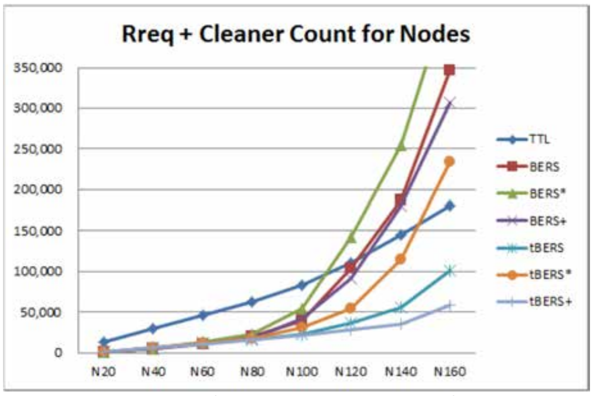


Figure 3. The number of RREQ and Chase packets for node count variation from 20 to 160(traffic sessions are 10 fixed, node speed is 20 m/sec max)

First, as depicted in the Fig. 3, the BERS series show better performances in accordance with their basic design concept, generating a less number of control packets than the TTL-ERS scheme at low or medium node density. However, if the node count increases over 120 nodes, where we can call high-density range, their control packet (RREQ + Chase) count sharply increases with the higher slope than the TTL-ERS curve. It means a rapid decline of their performance, i.e., an explosive rising of routing overhead or energy consumption. This phenomenon is observed remarkably in the SICP type models (BERS, BERS*, BERS+), earlier than RICP models. At 140 nodes, we can see SICP's control packet counts even exceed TTL-ERS model. It seems that the RICP type models could not avoid this rapid rise either, but the phenomenon starts at higher node density than the SICP type models case.

Through this phenomenon, we suppose that the Chase packets become another cause of broadcast storm in a high-density network, despite that Chase packet is used to cancel the flooding of RREQ of fulfilled route request. Although the BERS series models adopted the Chase packet to reduce their overhead or to lower power consumption than TTL-ERS model, these Chase packets ironically make the increased overhead or power consumption with a steep slope in case of high-density WiFi network than TTL-ERS. This phenomenon of BERS series models was not demonstrated by BERS studies so far.

Second, another aspect found from Fig. 3 is that the RICP models (tBERS, tBERS*, tBERS+) are much more energy efficient than SICP models (BERS, BERS* tBERS) or than the analytical estimation of previous studies. For examples in [5], the order of lower energy consumption (at 10 hops) is listed as “tBERS = BERS < tBERS* < BERS* < TTL-ERS”. It means that previous studies based on their analytic model have expected both tBERS and BERS to consume the same or a similar amount of energy [5][12]. That could be true in a network with low node density. However, our simulation on the realistic dense WiFi network shows the different result, that is “tBERS < tBERS* < TTL-ERS < BERS < BERS*” as illustrated in Fig. 3 and Fig. 5. In the range of 100 to 160 nodes especially, which is above medium-scale of network density, all the RICP models including tBERS* show better performances than all the SICP models. The more the nodes are added, there is the more performance gaps between RICP and SICP. At 160 nodes, the highest node count of this experiment, tBERS scheme generates only 1/3 of control packets and causes only 1/5 of routing overhead ratio (displayed in Fig. 10) as compared to BERS. This is an outstanding improvement of RICP type models when compared to SICP type models, and much more enhancement

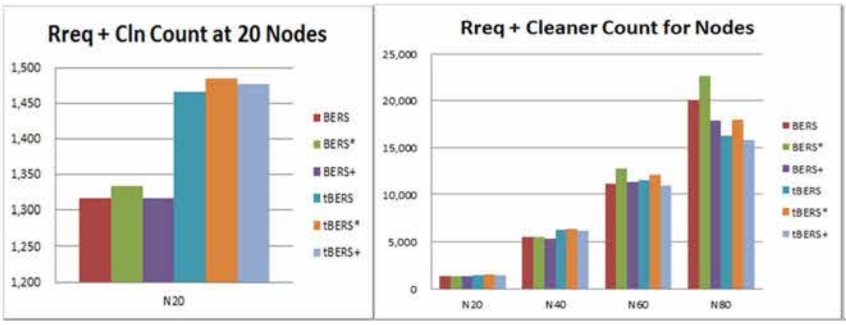


Figure 4 & 5. The number of Rreq and Chase packets for node count variation at 20 nodes/ from 20 to 80 nodes, with the fixed traffic session 10, node speed 20 **m/sec max.**

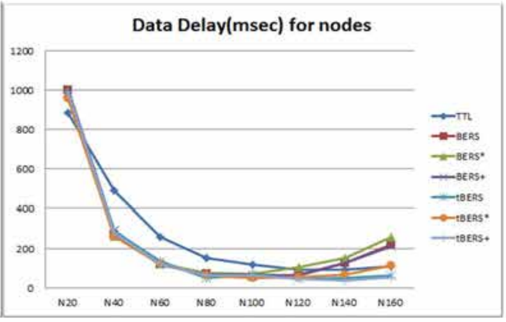


Figure 6. The end to end delay time for node count variation, with the traffic session 10, max node speed 20 m/sec.

than the expectation of the previous studies.

As described in the introduction, the RICP type schemes starts to cancel the flooding of fulfilled RREQ a little earlier - as earlier as a value of [Hr × NTT] - than SICP type scheme. We can conclude that this early cancellation of RREQ packet in RICP type models provides fast and stable protection from the broadcast storm before its explosion on high-density networks.

Even though the RICP models have better performance, they still cannot avoid performance degradation by the broadcast storm caused by Chase packet on the very highly dense network. In figure 3, we can see that the steep increase starts around 140 nodes. However, it is clear that RICP type models are more stable and perform better than SICP models even on the high-density network.

Third, the permission of a few more broadcasting packets on the low-density network can be significant harm on the high-density network. This phenomenon is observed in the case of BERS* or tBERS* as illustrated in Fig. 3 or Fig. 4(a partial enlargement of Fig. 3 with bar-graph, particularly at node count 20). In Fig. 4, BERS* or tBERS* model generates a few more RREQ packets than BERS or tBERS respectively on node count 20. It is natural due to the design of BERS*, tBERS* as described in section 2. Even if they would consume a little more energy, they could reduce Route Discovery Latency or End-to-End delay according to design concept[4][5]. However, as the node density becomes high, the number of RREQs in BERS* or tBERS* increases sharply and faster, and the difference of control packet numbers between BERS and BERS*, or between tBERS and tBERS* increases rapidly too as shown in figure 5. At last, after middle node density, BERS* comes to the most critical aggravation of its overhead among the other models we analyzed, and tBERS* coms to same situation among the RICP models as illustrated in Fig. 1.

It means that allowing little more broadcasting packets in low node density induces a disaster of broadcast storm on the dense network, as a negative leverage effect. Moreover, BERS* model shows the longest End-to-End delay in the all models, and so does tBERS* model among the RICP models, due to the network congestion as we described in the delay analysis section. That is entirely contrary to the expectation of the proposer of [4][5].

Meanwhile, BERS+ or tBERS+ displays some better performance than the BERS or tBERS, respectively, as depicted Fig. 3. As the authors of [7] analyzed, BERS+ or tBERS+ models somewhat improved their performance from their original model, and the effect of it can be more certainly displayed on a dense network, although it is not significant in the low-density range. As BERS+, tBERS+ generally show better performance in any range of node density, so we will keep this result without further mention.

2) Data Packet End-to-End Delay: Fig. 6 and 7 show the End-to-End delay of BERS series models for node count variation on the WiFi MANET, and they also reveal that the performances of BERS series models over the WiFi network are quite far from the theoretical estimation of the proposal.

The proposers of BERS predicted that the scheme would have a slightly higher delay cost than the TTL-ERS, and they developed further models focused on the refinements of time efficiency, such as BERS*, tBERS, and tBERS*. Therefore, they suggest the ranking of models by Path Discovery Latency as "tBERS* < BERS* < tBERS < TTL-ERS < BERS," (where the latency is the delay between the time the source node send the RREQ and the time the flooding is actually stopped). However, the graph in Fig. 6 and Fig. 7 drawn from our research shows in a large perspective that each model algorithm can't control the routing latency properly, but that the node density of the network influence it mostly.

Generally, when the network starts as a low density with about 20 nodes, all schemes show the severe delays due to the separation of network or disconnection of communication channels. Here TTL-ERS model, which broadcasts the RREQ the most frequently by the source node, shows relatively better performance on latency than BERS series models.

But as the node count gradually increases, the delay performance improves very rapidly. When the network constructed with 80 to 100 nodes, all the BERS series schemes show the optimal delay performance, and they all have similar delays with only slight gaps between each other. Here the number of neighboring nodes (NNN) can be estimated as 5.9 to 7.7 when the number of nodes is 80 to 100 as described above chapter. It means that optimal network of NNN, 6~8 as mentioned by [15][16][17], is also established in the AODV network equipped with the BERS series. In this optimal range of node density, TTL-ERS shows worse delay performance than BERS series models because it should broadcast much more RREQ control packets, but with the high delivery rate.

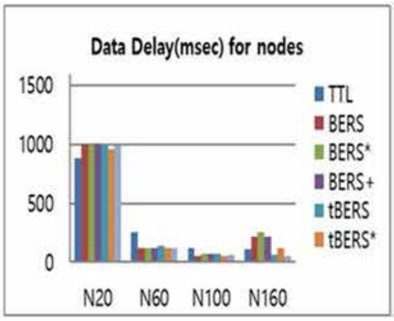


Figure 7. The end to end delay time for node count (10 session, 20 m/sec)

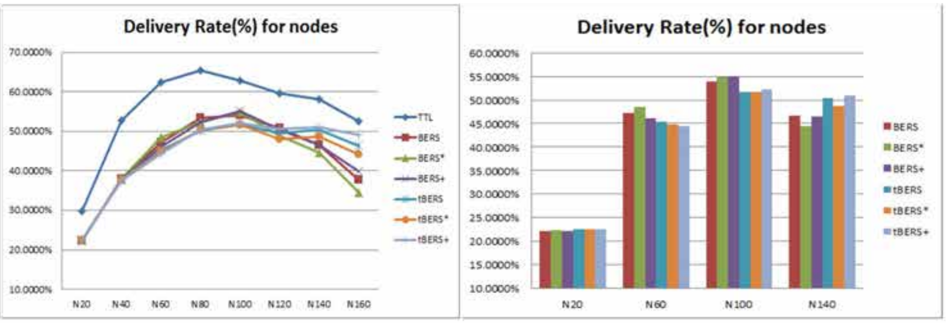


Figure 8 & 9. Delivery Rate for node count variation, with the traffic session 10, max node speed 20 m/sec.

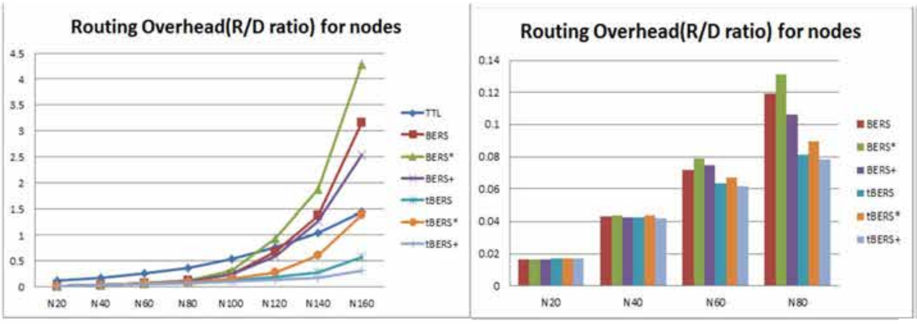


Figure 10 & 11. Routing Overhead Ratio for node count variation, with the traffic session 10, max node speed 20 m/sec.

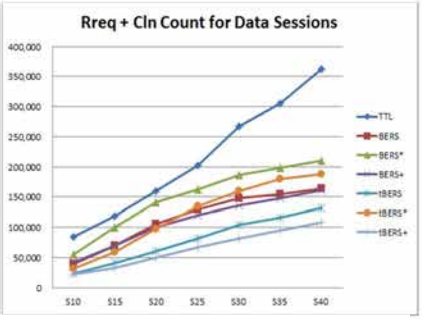


Figure 12. The Number of Rreq and Chase packets for data session variation (100 nodes, max. 20 m/sec)

When it comes to a high-density network, the delay performance of each model depends more on how much the network is congested, regardless of the intended difference of each initial design of the model. Therefore, BERS* scheme rather shows the longest delay among SICP models, because it broadcasts the most number of RREQ packets among them. In the same way, tBERS* model shows the longest delay among RICP models, and SICP models generally show longer delays than RICP models.

In this highly dense WiFi network, the delay performance of each model in order is tBERS < TTL-ERS < tBERS* < BERS < BERS*, which appears to be an entirely different result from the original intention of the designer.

3) Data Packet Delivery Rate (Loss Rate): As illustrated in Fig. 8 and 9, the Delivery Rate is much more influenced by the node density of the network than by the own algorithm of each model. If the node density is low as in Fig. 8, Delivery Rate goes down due to network separation or loss of end to end connection. As the number of nodes increases, the Delivery Rate improves very quickly, and it reaches to the peak at the optimal node density (80 to 100 nodes) previously mentioned. As the node count keeps increasing to high node density, the Delivery Rate decreases again due to channel saturation occurred by severe contention or network congestion. In Fig. 8 and 9, we can see that the node count for optimal network that gives the maximum delivery rate or the maximum throughput in this network is 80 to 100 nodes.

Interestingly, the delivery rate is roughly proportional to the number of RREQ in case of the low or mediate node density (below the optimal value) network. Fig. 8 and 9 display this characteristic. Apparently, the larger amount of RREQ packet in a low-density network gives more chance to find the path, so this makes a higher delivery rate despite more energy consumption. Therefore, it is not always the best choice to minimize RREQ packets. However, the delivery rate is inversely proportional to the number of RREQs at the high node density network due to channel contention or congestion naturally.

4) Throughput **:** Because there is no variation of data session and data rate, it shows a similar pattern with data delivery rate.

5) Routing Overhead Ratio **:** Fig. 10 and Fig. 11 show the routing overhead ratio of B series-ERS and TTL-ERS models. It draws the analogous pattern with Fig. 3 and Fig. 5. But the ratio value over 1.0 indicates that the number of control packets is greater than the number of data packets. The initial value of it at low density is very small as shown in Fig. 11.

In Fig. 10, we can see, at the 140 nodes network, all SICP type models have big overhead where the number of control packets exceeds the number of data packets. However, in RICP type method except for tBERS*, routing overhead ratio does not rise over 1.0 within the full range of node density experimented. When the number of nodes is 160, in terms of routing overhead ratio, tBERS was five times better than BERS, and tBERS* was three times better than BERS*, and tBERS+ was eight times better than BERS +.

B. For the data session variation

Fig. 12 to Fig. 16 show the performance metrics for data session variation with 100 nodes and 20 m/sec mobility fixed.

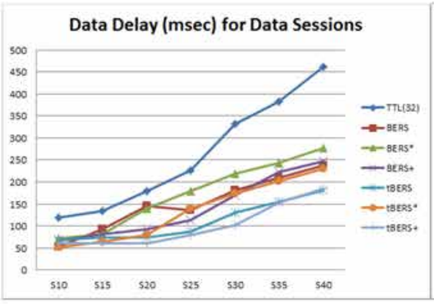


Figure 13. Data End-to-End Delay for data session variation (100 nodes, max 20 m/sec)

Figure 14. Delivery Rate for data session variation. (100 nodes, max. 20 m/sec)

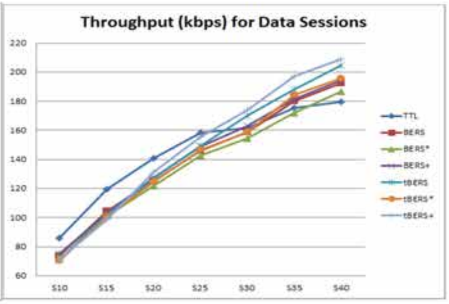
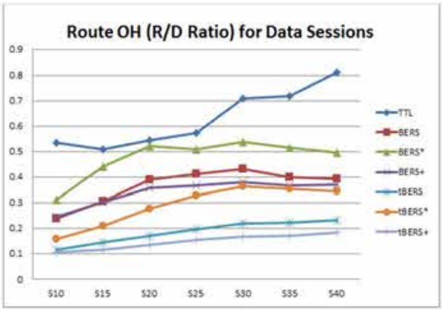


Figure 15 . Throughput for data session variation. (100 nodes, max. 20 m/sec)



16. Route Overhead Ratio for data session variation (100 nodes, max. 20 m/sec)

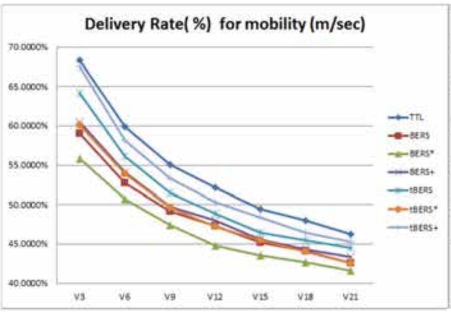


Figure 17. Route Overhead Ratio for mobility level (100 nodes, 25 data sessions)

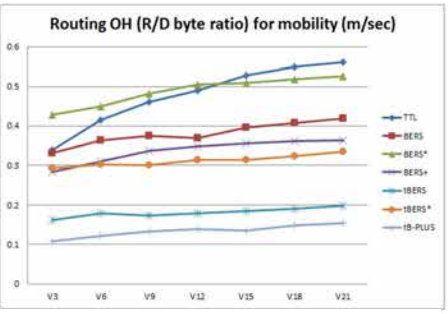


Figure 18. Route Overhead Ratio for mobility level (100 nodes, 25 data sessions)

1)* The number of RREQ and Chase Packets *: As appeared in Fig. 12 and Fig. 16, control packet count, energy consumption or routing overhead ratio of all the models go up when the data session increase. Among those models, TTL-ERS shows the largest increment (27.7%), followed by tBERS*(18.9%), and BERS*(18.2%). Also, SICP type models show larger increments (e.g. BERS 15.5%) than RICP models (e.g. tBERS 11.6%) along with session increase.

Here, we can find that, at optimal node density, the models which create a large number of control packets tend to have high overhead increments for session changes. So TTL-ERS is most sensitive against the session variation or traffic amount variation, the SICP type models are next, and the RICP type models are the most stable. The order of routing overhead ratio at 40 data sessions (among the 100 nodes) was tBERS+ < tBERS < tBERS* < BERS+ < BERS < BERS* < TTL-ERS.

2) Data Packet End-to-End Delay : As the number of sessions grows, the End-to-End delay also increases, as shown in Fig. 13. Again, the TTL-ERS model shows the largest increase, and the second one is BERS*. SICP type models show a bigger increase than RICP models, and tBERS* model shows the biggest increase among the RICP models.

3) Data Packet Delivery Rate (Loss Rate) : Data packet delivery ratio decreases as appeared in Figure 14. TTL-ERS model shows the largest decrease(30%), and the second largest one is of BERS*(20.6%). SICP type models show a bigger decrease than RICP models, and tBERS* model shows the largest decrease among the RICP models. It is a similar pattern with delay metrics above.

4) Network Throughput : Overall throughput increases as shown in Fig. 15, and that means the entire network may not be saturated despite the increasing data session in this experiment. RICP type models those create less control packets than SICP models show a larger increase in throughput for they have more room to accommodate session increment. However, the TTL-ERS, which generate the largest amount of control packets, shows the smallest increase in throughput.

5) Routing Overhead Ratio: Fig. 16 shows the routing overhead ratio for session increase, similar pattern to Fig. 12. The TTL-ERS has the largest increase, followed by SICP type models and RICP type models. So SICP type models are more vulnerable to session variation than RICP type. In other words, we can see that the models which generate the most control packets are worst to accommodate the session variation.

C. Analysis on the mobility variation

Fig. 17 to 18 illustrate all the performance metrics for the variation of mobility level from 3m/sec to 21 m/sec. The node count is 100 with 25 data sessions.

C.E Perkins, one of the AODV designers, illustrates some graph in his book which shows that mobility level variation does not significantly influence the routing overhead (in terms of RREQ, RREP, RERR) when the node moves over 5m/sec. And also he declared "the delay is more a factor of network topologies and the queueing delay at the individual nodes," [1]. The result of this study also demonstrated a similar idea, so we do not depict the number of control packets and delay for mobility in detail.

As shown in Fig. 17, The Delivery Rate (or Throughput) is significantly affected by mobility. The values decrease distinctively for the increase of mobility in all the models. In those, TTL-ERS model shows particularly the worst degradation (-22.1%), followed by RICP models (e.g., tBERS -19.6%), and then SICP models (e.g., BERS -16.5%)

Fig. 18 is a graph of routing overhead ratio for mobility level variation. This metric keeps increasing too due to the decline of delivery rates (or throughput). So the overhead ratio of TTL-ERS model increases the most, whereas the RICP models' overhead increases the least. At the highest speed (21m/sec) of 100 nodes network, their rank was tBERS+ < tBERS < tBERS* < BERS+ < BERS < BERS* < TTL-ERS. It is same that we found already in case of data session variation.

Therefore, the response of each model to mobility variation is similar to that of data session changes. The RICP models are most adaptable to mobility level, the next is the SICP, and the TTL-ERS is the most vulnerable.

V. CONCLUSION

In this paper, we modelled the recently proposed schemes of BERS series in the AODV protocol on the WiFi MANET and run a lot of simulations for the variation of the node density, data sessions and mobility level through NS-3 simulator. Primarily, this study compared the SICP(Source node Initiated Chase Packet) type BERS schemes which have not been experimented enough on the dense WiFi network, and the RICP (Reply node Initiated Chase Packet) type schemes for which there have been no realistic WiFi network simulations in previous researches until now.

The result of this study reflecting a lot of realistic situations of AODV/WiFi MANET is much different from the general expectations of previous studies conducted by mathematical approach or analytical simulations. Also, the graphs obtained through our simulation considering a wide range of node densities show broader insights and new aspects that did not appear in the BERS WiFi network simulations which have been conducted only at low node densities relatively.

The several points of results were described in the previous chapter with in-depth analysis and discussion.

One of those points is that the Chase packet used by BERS series models for flooding cancellation can be another significant cause of broadcast storm on the high node density network ironically. When the network has a low node density, the BERS series models seem to be working well with lower routing overhead than TTL-ERS. But in the high node density network (i.e. network with a large number of nodes), the routing overhead of the BERS series increases exponentially and other performance metric values get worse rapidly too. This phenomenon happens early in SICP type models, starting after the medium level node density. In case of RICP type models, the performance degradation does not appear until the node density gets significantly higher than SICP type case, yet they could not avoid the degradation either in the end.

Moreover, the RICP type models show much higher performance improvement than the analytical expectations of previous studies on the dense WiFi network. Because the RICP type models can start the cancellation of fulfilled RREQ's broadcasting earlier than the SICP, this leads to sooner and more stable protection of broadcast storm before its explosion on high-density networks. So, in terms of routing overhead ratio, the RICP type models show 3 ~ 5 times better performance than SICP model, as described in the chapter above.

As for the Path Discovery Time or End-to-End delay, we discussed that these performance values of BERS series models over the WiFi MANET are quite far from the theoretical prediction of the designers. This is because, in the realistic MANET, the delay performance is more influenced by the network topology, especially the number of neighbor nodes or the node density, than by each algorithm.

With the viewpoint of the session or mobility variation, this study concluded that the models which generate a larger number of control packets show the more performance deterioration for the increase of session or mobility. So the RICP type models are most adaptable to both variations, the next is the SICP, and the last TTL-ERS is the most vulnerable. The Overall overhead performance order could be evaluated as follows: tBERS+ < tBERS < tBERS* < BERS+ < BERS < BERS* < TTL-ERS at optimal node density, and tBERS+ <tBERS < tBERS* <TTL-ERS < BERS+ < BERS < BERS* at the highest node density as depicted in Fig. 10.

Meanwhile, this study was examined on the AODV protocol. So the other protocol could be considered for BERS series models. Also, if we can implement a network with more high density, more data session or more wide area, we would observe the further performance of SICP, RICP type models in extensive ranges. Those points would be applied to our further researches.

ACKNOWLEDGMENT

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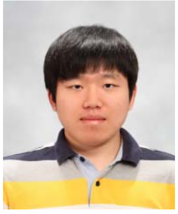

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