

SRAD: A Novel Approach to Seamless Routing for Wireless Ad Hoc Networks

Saad Allawi Nsaif*, Sang Yoon Park**, Jong Myung Rhee***

*Verizon Communications, Cary, NC 27513 USA

**Department of Electronics Engineering, Myongji University, 116 Myongji-ro, Yongin 17058, Korea

***Corresponding Author, Department of Information and Communications Engineering, Myongji University,

116 Myongji-ro, Yongin 17058, Korea

saad.allawi1@gmail.com, sypark@mju.ac.kr, jmr77@mju.ac.kr

Abstract— In this paper, a novel multiroute approach called seamless routing for wireless ad hoc networks (SRAD) is proposed. The SRAD approach establishes two disjoint routes between each connection pair in the network. As a result, a full wireless mesh network is established among the mobile nodes. Consequently, the destination node receives two redundant frame copies from each sent frame, each one via a disjoint route. The destination node consumes the fastest copy that reaches it and then deletes the subsequent copy delivered via the second route. Eventually, each node achieves a zero-recovery time in the event that one of these established routes fails because it will be able to receive any lost frame copies via the other route without interruption. In the SRAD approach, route choice depends on selecting the lowest BER values for the discovered routes between each node pair. These routes are also disjointed to provide seamless redundancy. This selection strategy has the advantage of reducing the number of received error-frames—which, consequently, reduces the retransmission process—therefore, the received frames have a high quality unlike in other approaches.

Keywords— wireless communication, bit error rate, ad hoc networks, SRAD, Ethernet

I. INTRODUCTION

Wireless ad hoc networks are collections of nodes equipped with wireless transceivers that communicate exclusively over a common wireless channel. Due to the nature of the wireless channel, each node can only communicate directly with a few other nodes lying in its neighbourhood. On the other hand, the traffic requirements of the network are such that distant nodes may need to exchange data. Therefore, the nodes intermediate to such communicating pairs must relay data in a multihop fashion. Therefore, the establishment of the network and its operation must be exclusively over the wireless channel, and in a distributed and decentralized manner [1].

Ad hoc networks should be constructed rapidly. Contrary to cellular networks, where an extensive infrastructure must be installed, ideally, wireless ad hoc networks should be formed automatically whenever any number of users happen to be in proximity to one another. This speed of deployment is very important in a variety of applications, such as networks used in military or autonomous vehicle operations. The lack of

additional infrastructure also means that ad hoc networks are inherently inexpensive: there is no need to purchase or install base stations (perhaps in costly rented premises). Therefore, if communication needs can be satisfied using an ad hoc network, where nodes act as their own base stations, there is no need to use more expensive cellular topologies.

Multipath designs represent a promising method for routing wireless mobile ad hoc networks. This type of routing achieves load balancing and is more resilient to route failures. Multipath routing allows the establishment of multiple paths between a pair of source and destination nodes [2]–[5]. It is typically proposed to increase the reliability of data transmission or to provide load balancing. Numerous multipath routing protocols have been proposed for wireless mobile ad hoc networks, such as split multipath routing (SMR) [6] and ad hoc on-demand multipath distance vector (AOMDV) [7]. Tarique et al. [8] investigated multipath routing protocols for mobile ad hoc networks (MANETs) and provided a checklist to enable network designers choose a multipath routing protocol appropriate for the network's application objectives. However, the main goal of such protocols is to provide multiple routes to minimize route recovery process and control message overheads. Multiroute protocols are used to distribute data frames into multiple routes of active sessions. This traffic distribution efficiently utilizes available network resources and prevents nodes along the route from becoming congested in situations of heavily loaded traffic [6].

In this paper, we propose a novel multiroute approach called seamless routing for wireless ad hoc networks (SRAD) with BER metric [9] instead of shortest path (SP) metric [10], [11]. Our approach provides seamless communication for each source–destination connection pair. This is accomplished by establishing two disjoint routes between each connection pair in any ad hoc network. Consequently, the destination node receives two redundant frame copies from each sent frame (one from each route). The destination node consumes the fastest copy to reach and subsequently deletes the second copy that is delivered later via the other route. This approach offers zero-recovery time for the destination node in the case where one of the routes fails. However, route selection depends on the BER values of the routes. In other words, the routes are selected

depending on their quality. This feature reduces the received error-frames and thereby the retransmission process for the error-frames; consequently, frame latency is reduced compared to other approaches such as the SP-based routing protocol.

II. SRAD APPROACH

A. SRAD Concept

The aim of the SRAD approach is to provide seamless wireless communication redundancy for each pair of nodes in an ad hoc wireless network. As a result of applying SRAD approach on any network, a full wireless mesh network is established among the nodes. The source node of each connection pair duplicates the required frame to be sent, and then sends each copy via a different route to the corresponding destination node of that pair. This approach allows all nodes communicate with one another at high quality and without interruption. The SRAD uses several special frames during the setup and monitoring phases. Each of these frames has a unique Ethertype code and also has a sequence number.

The SRAD approach is applicable to industrial applications that require zero-recovery; and for any mission-critical or real-time applications and systems.

B. SRAD Setup and Operation

1) First Phase (Node Discovery): According to the link layer of IEEE 802.11 [12], each node senses any adjacent nodes; the nodes then exchange MAC address and possibly some authentication information to trust each other before considering each other. As a result of this phase, each node builds an adjacent nodes (AdN) table containing the MAC addresses of all adjacent nodes, including the BER values of their links.

2) Second Phase (Route Discovery): In this phase, all the network nodes discover the possible routes to each corresponding node in the network.

3) Third Phase (Route Selection): After each node sends a route discovery (RoD) frame to each corresponding node in its network (which is considered destination nodes in this case), each destination node selects the optimum routes that connect it with each source node from which it received an RoD frame.

Table 1 shows an example for the routes table of node A in Figure 1 when it has established two disjoint routes with node D. Note that each node in the network has routes and connection pair (CP) tables. Routes table is used for sending frames to the destination nodes of its connection pairs, whereas the CP table guides the node in forwarding the passing frames of other connection pairs. All nodes employ the same approach when communicating with each other.

TABLE 1. ROUTES TABLE FOR NODE A OF THE NETWORK SHOWN IN FIGURE 1

No.	Src. MAC	Dst. MAC	Seq. #	RoC
1	A	D	xxx	B
2	A	D	xxx	H

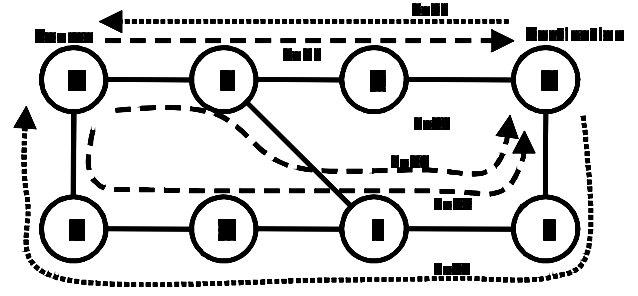


Figure 1. Available wireless links at a certain moment of time for those nodes, and how the RoD and route confirmation (RoC) frames are traveling in the network to establish two disjoint routes for the connection pair of A-D

4) Fourth Phase (Utilizing Redundant Routes): Eventually, each node only consumes the first received copy, and deletes the second copy of that frame delivered from the other route. However, the node needs to recognize whether or not it has received that copy so that it can consume the other copy from the second route. For that, each of the connection pair's nodes establishes a counter for each established selected route. Each node consumes the fastest-received frame as long as the frame is error-free. In other words, if the counter of the faster route is equal to or greater than that of the second route, then the node consumes the frame received from that route and deletes the other copy. Therefore, no duplicated frames are received. However, if the faster route experiences a problem or failure, then its counter stops or at least increases slowly such that it is less than the counter of the second route. In that case, the node consumes the incoming frames from the second route and deletes those of the first route. This behaviour can be represented in the following expression:

If counter 1 $\geq$ counter 2, then consumes the frames of route 1, else consumes the frames of route 2.

We previously introduced this approach of deleting the redundant received frame, termed Seamless Ethernet approach [13]. We used this approach to avoid adding a sequence number inside each sending frame, which would otherwise increase the traffic volume across the network. Therefore, in the SRAD approach, the standard Ethernet frame layout can be used without modification.

At this point, all the nodes have established redundant routes with each other and use them for communication.

III. ANALYTICAL PERFORMANCE

In this section, the SRAD's performance is determined from the point view of BER and end-to-end delay metrics. The BER of a route can be determined using [9]

$$BER^{(n_h)} \cong 1 - \prod_{i=1}^{n_h} [1 - BER_{link}(i)] \quad (1)$$

where n_h is a route consisting of h hops or links. However, in a connection pair, the destination node starts comparing the IDs of each received RoD frame copy; when it finds several disjoint routes, it calculates their BER values. If two or more routes have the same BER values (practically, this is very difficult),

the destination node considers the route that its RoD frame copy reached first.

Now, let us assume that at a certain moment of time we get several mobile nodes that are moving in a group, as shown in Figure 2. The available wireless links among the network nodes are shown in the figure, with their distance lengths and BER values. Assume all the wireless links have a link capacity of 11 Mb/s and the node processing rate is 100 Mb/s. In this network, assume node A needs to send a stream of frames of size 1,522 bytes to node F. To achieve this goal, first nodes A and F establish routes between each other and then the send the required frames. In this example, if the SRAD approach is applied, then node F receives six RoD frame copies, each of them passed through a route as shown in Table 2, assume that the RoD frames of these routes are received sequentially as arranged in Table 2.

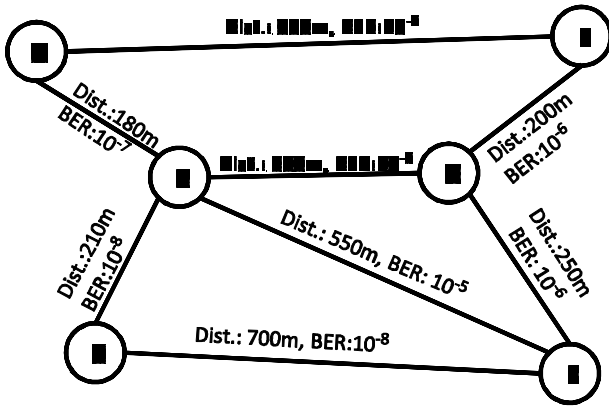


Figure 2. Available wireless links at a certain moment of time

TABLE 2. POSSIBLE ROUTES BETWEEN NODES A AND F

No.	Routes
1	A-B-F
2	A-B-D-F
3	A-E-D-F
4	A-B-C-F
5	A-E-D-B-F
6	A-E-D-B-C-F

Node F then calculates the BER of each route and selects the route with the lowest BER (which is A-B-C-F) as the first candidate route, then compares the following routes with the first route:

- A-B-D-F
- A-E-D-F
- A-E-D-B-C-F

Node F selects the route of A-E-D-F as the second route for the connection pair A-F because this route has no common node with the first route A-B-C-F. Later, node F sends two RoC frame copies, one into each route to confirm the route selection.

Thereafter, node A duplicates each frame that needs to send it to node F and send these copies out, one to each route (to node B and node E).

Now, node F receives two copies from each sent frame—one from each direction, takes the copy that arrives first and deletes the second copy. Generally, we can establish criteria for the highest acceptable BER value of each route to avoid selecting a noisy (i.e., useless) route. However, by using (1), we can calculate the BER value for each of the selected routes, as follows:

$$BER^{(13)} \cong 1 - \prod_{i=1}^{13} [1 - BER_{link}(i)] = 1.19 \times 10^{-7} \quad (2)$$

$$BER^{(23)} \cong 1 - \prod_{i=1}^{23} [1 - BER_{link}(i)] = 2.09 \times 10^{-6} \quad (3)$$

IV. SIMULATION PERFORMANCE

The OMNeT++ network simulator [14] was used to simulate and compare the BER performance of the SRAD to that of SP-based approach. An ad hoc wireless network with 21 nodes uniformly distributed across the network coverage area of 1000 m × 1000 m was adopted. Nodes moved with a maximum speed of 10 m/s and in random directions in the selected area. The BER value of each link in the network was randomly set with a uniform distribution between 10^{-4} to 10^{-8} . Link capacity was set to 11 Mb/s. Each node had a coverage area of 250 m.

The frame size was 1,522 bytes. Each simulation run was executed for 100 seconds. Average BER value of each run was the average BER value of all the selected routes of all nodes in the simulated networks.

Figure 3 shows the average BER per established routes under SRAD approach and SP-based routing protocol. The SRAD's performance is significantly better than that of SP-based routing because the SP is always sending over the shortest path even when the BER of that path is low, whereas the SRAD only sends over the path with the better BER. In addition, when the number of nodes increases, the performance of SP-based routing is reduced, whereas that of SRAD is increased, except it undergoes only insignificant changes.

Finally, SRAD provides full disjoint paths among each communication pair if those are available.

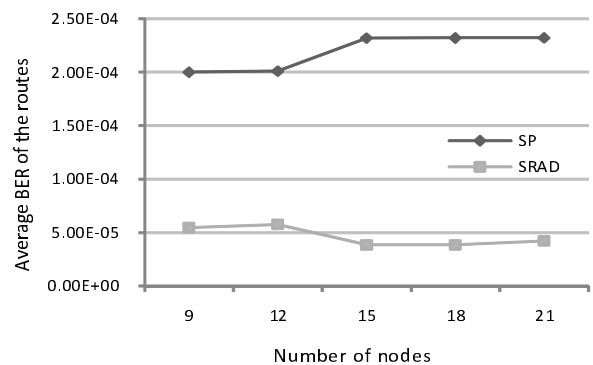


Figure 3. Average BER under SRAD and SP with respect to number of nodes

V. CONCLUSION

In this paper, we proposed a novel approach called SRAD to establish two wireless routes between each node pair available in an ad hoc network. These routes are determined by the quality of that route, and in this paper, BER value was selected as the metric for route quality. Each node uses these routes seamlessly without interruption. The node receives frames with zero-recovery time in the case that one of the established routes in a connection pair fails.

The SRAD approach with BER metric shows better performance than the SP-based routing protocol. In the SRAD approach, the standard Ethernet frame layout can be used without any modification because its frame does not need to add sequence numbers or other fields, only when sending data frames, which in turn reduces the network traffic.

The SRAD approach is of interest for some industrial applications that require zero-recovery features. It is also applicable to any mission-critical or real-time applications and systems—especially for autonomous vehicle or military purposes. For these activities, communication interruptions during operations are unacceptable.

Further studies will be conducted to compare SRAD's performance against various aspects of multiroute protocols.

ACKNOWLEDGMENT

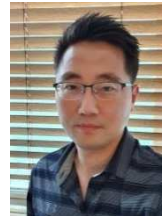
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Saad Allawi NSAIF received his B.Sc. degree in Electrical Engineering from University of Baghdad, Iraq, in 1999 and his M.Sc. degree in Computer and Control Systems from the same university in 2002. After graduation, he joined the University of Baghdad as an Assistant Lecturer. Later, he joined the Iraqi Ministry of Defense in 2004. He was the Director of the Command and Control Systems (C2) for 7 years. His contribution in designing, developing, and establishing the Iraqi C4I systems is well-known, especially with the Iraqi Defense Network (IDN). In Feb. 2015, he received his Ph.D. in Information and Communications Engineering from Myongji University, South Korea. Currently, he is a Manager at Verizon USA.. His current research interests are AI, clouds, and networking design.



Sang Yoon PARK (S'03-M'11) received his B.S. degree in electrical engineering and his MS and PhD degrees in electrical engineering and computer science from Seoul National University, Seoul, Rep. of Korea, in 2000, 2002, and 2006, respectively. He joined the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, as a research fellow in 2007. From 2008 to 2014, he was a research scientist with Institute for Infocomm Research, Singapore. Since 2014, he has been with the Department of Electronic Engineering, Myongji University, Yongin, Rep. of Korea, where he is currently an associate professor. His research interests include design of dedicated and reconfigurable architectures for low-power and high-performance digital communication systems.



Jong Myung RHEE received his PhD from North Carolina State University, USA, in 1987. After 20 years at the Agency for Defense Development in Korea, where he made noteworthy contributions to C4I and military satellite communications, he joined DACOM and Hanaro Telecom in 1997 and 1999, respectively. At Hanaro Telecom, which was the second largest local carrier in Korea, he served as Chief Technology Officer (CTO) with a senior executive vice-president position. His main duty at Hanaro Telecom was a combination of management and new technology development for high-speed Internet, VoIP, and IPTV. In 2006, he joined Myongji University, and currently, he is a special mission professor in the Information and Communications Engineering Department. His recent research interests are centered on military communications and smart grids, including ad-hoc and fault-tolerant networks. He is a member of IEEE and KICS.