Enhanced Multipath Routing Protocol using Congestion Metric in Wireless Ad Hoc Networks

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Abstract. Transmission over wireless ad hoc networks is a challenging problem, because the wireless channel is characterized by limited bandwidth, multihop connectivity, mobility of nodes, and dynamically varying network topology. Current unipath routing protocols result in performance degradation in mobile networks due to unreliability of the wireless infrastructure and mobility of nodes. Multipath routing is an attractive alternative for scalable and multiple sub-streamable multimedia traffic under highly error-prone and resource-depleted network environments. However, existing multipath-capable routing protocols cannot split a single data flow into several sub-flows over a multipath, because these routing protocols use, mostly, an alternate path scheme that provides a secondary path in the event of link failure of the primary path. The Split Multipath Routing (SMR) protocol, which is a major multipath routing protocol based on Dynamic Source Routing (DSR) and uses decentralized transmission over multipath. In enhanced performance, Split Equal-cost Multipath Routing (SEMR) based on SMR is proposed, by introducing 'congestion path metric' as a novel metric, which can identify whether the path contains a bottleneck node and guide the selection of other non-congested paths in the path-selecting process. In using proposed concept, superior performance in comparison with SMR and DSR, can be achieved.

1 Introduction

Mobile Ad Hoc Networks (MANETs) consists of a collection of wireless mobile nodes which dynamically exchange data among themselves without reliance on a fixed base station. MANET nodes have a high degree of mobility and are typically distinguished by limited power, processing, and memory resources. In such networks, wireless mobile nodes may enter and leave the network dynamically. Due to the limited transmission range of wireless network nodes, routing is a crucial issue in the design of MANETs.

Previous unipath routing protocols, such as DSR[2], AODV[3], TORA[4], and ROAM[5], in MANETs do not solve load balancing, fault-tolerance, and route resilience problems. However, the multipath routing protocol provides various advantages in addition to solving the problems of the unipath routing protocol. The multipath routing protocol is able to support superior performance in mobile network conditions [1]. Multipath routing protocols based on AODV (e.g., AODV-BR[6] or AOMDV[7]), or based on DSR (e.g., MSR[8] or MDSR[9]), contain a primary path and one or more alternate paths. Although the primary path may be broken, the connection is maintained by using an alternate path, resulting in an improvement in overall performance. However, multipath routing algorithms using an alternate path, provide fault-tolerance, not load balancing. In addition, because there are many link failures in high-mobility or in highly node-densed networks, previous multipath routing algorithms are not effective in terms of path maintenance. Hence, an equal-cost multipath routing algorithm such as split multipath routing (SMR) is proposed in order to solve both load balancing and fault-tolerance problems. [10]

In this paper, a new path metric (so called congestion path metric) is presented and applied to the equal-cost multipath routing algorithm by enhancing the SMR algorithm. It is called Split Equal-cost Multipath Routing (SEMR). SEMR reduces the congestion degree by dispersing a traffic-stream into multiple paths. Therefore, overall network performance in high-mobility networks is enhanced.

The subsequent sections of this paper are organized as follows. In Section 2, a review of SMR, as a referenced equal-cost multipath routing algorithm, is provided. In Section 3, a multipath routing algorithm where a new congestion path metric is applied, is presented. In Section 4, a performance evaluation is presented. This paper is concluded in Section 5.

2 The Problems of SMR as an Equal-Cost Multipath Routing

SMR, based on DSR, is a reactive multipath source routing protocol and equal-cost multipath routing protocol. SMR has superior throughput over DSR, because it uses maximally disjoint two paths in MANETs, so that data connections are maintained. SMR has a greater initial path configuration time and control packets than DSR, and has, lower end-to-end delay and overhead than DSR. The basic idea of SMR is similar to DSR, and is used to construct maximally disjoint paths. Unlike DSR, intermediate nodes do not maintain a route cache, and do not reply to Route Request (RREQ) messages. This allows the destination to receive all possible paths so that it can select maximally disjoint paths. The destination uses the shortest delay path metric. The first path is the shortest delay path, and the second path is a maximally disjoint path. SMR is suitable for high-mobility networks, because link failures often occur in high-mobility networks. In SMR, fault-tolerance is enhanced by selecting the maximally disjoint path. In addition, higher load balancing performance through split data transmission is demonstrated.

As a general routing protocol in MANETs, SMR selects the shortest delay path and maximally disjoint path. Therefore, it may create a bottleneck in terms of considering many data sessions. A data session includes the total multiple paths for multiple data sub-streams per each user connection. For example, if one node belongs to the shortest delay path, there is a high probability that the node belongs to the shortest delay path of another data session. Therefore, it is required to consider avoiding congested nodes so that transmission errors can be reduced. Therefore, the SMR algorithm is modified to enhance network performance.

3 Proposed Split Equal-Cost Multipath Routing (SEMR)

In SMR, it may be true that data paths are concentrated on one node in highly node-densed networks, due to using the shortest delay path metric such as DSR. To overcome these challenges, SEMR uses the least congestion path metric instead of the shortest delay. The congestion at each path can be estimated, as the congestion degree in each node in the path is known.

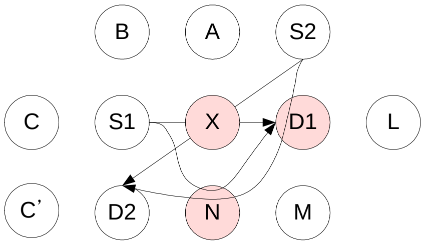

Fig. 1. Path Selection in SMR

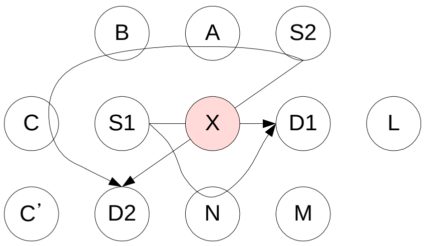

Fig. 2. Path Selection in SEMR

As conceptual diagrams, Fig. 1 and Fig. 2 demonstrate congestion nodes when selecting two paths in SMR and SEMR, respectively. There are two data sessions, i.e., (S1, D1) and (S2, D2), and each one has two paths. Both SMR and SEMR transmit data through two paths (S1-X-D1 and S1-N-D1) as a first data session. The second data session is established from S2 to D2. SMR selects the S2-X-D2 path as the first path of the second data session, and S2-D1-N-D2 as the second. Therefore, there are three congested nodes (X, D1, and N node) in SMR. (See Fig. 1). SEMR selects the S2-A-B-C-D2 path as the first path, because the S2-X-D2 path is a congested node (X node). The S2-X-D2 path, is a maximally node-disjoint path, is selected as the second path. Therefore SEMR selects the S2-A-B-C-D2 path in Fig. 2, instead of the S2-X-

D2 path in Fig. 1. This results in SMR containing three congested nodes, and SEMR only containing a single node. It means that SEMR has lower probability than SMR, when network congestion occurs. Therefore, SEMR enhances load balancing, fault-tolerance, and overall performance.

3.1 Congestion Path Metric

When data is transmitted from source to destination node, all data is passed through intermediate nodes in each path. If the shortest delay is used as a path metric, the path containing the smallest hop count is selected. This means that if many paths will be concentrated on one node, the probability of congestion is high. For example, if the shortest delay is considered as a path metric, connection pairs (A →A', B →B', C →C', and D →D') cerate the X node congestion node, as presented in Fig. 3. Therefore SEMR minimizes the bottleneck probability using a congestion path metric.

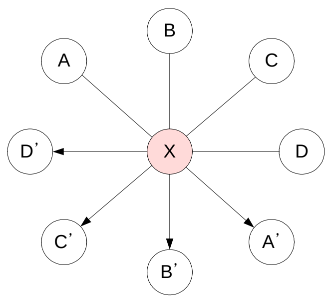

Fig. 3. In case of generated bottleneck node

Although each node does not transmit data to other nodes, it plays a role in intermediate nodes in MANETs. However, data that can be simultaneously processed is limited, because each node has limited resources (CPU clock, bandwidth, propagation range, power, and so on). Processing data in each node can be called Node Congestion (NC). NC in SEMR can estimate processing data not only at the current time, but also in the future. (Refer to Section 3.2) In addition, Path Congestion (PC) is computed using NC . PC , containing *n* intermediate nodes is,

$$PC = \sum_{i=1}^{n} NC_i \ . \tag{1}$$

, where NC_i is the node congestion value of i^{th} node.

In Eq. (1), the PC value of each path can be expressed as a summation of NC s in the intermediate node. A high PC value means that the probability of a bottleneck is high, because the PC value is directly proportional to the future transmitted data size. Therefore, SEMR can select a path that has the smallest PC value, as the smallest bottleneck probability. That is one of the different features in comparison with DSR or SMR.

3.2 Path Establishment

SEMR, based on SMR, is an equal-cost multipath routing protocol. The source generates the RREQ message to be transmitted to the destination when there is no path information, which is similar to SMR. The flooded RREQs are duplicated by intermediate nodes. Many RREQs reach the destination node, and the destination selects the least congested path and multiple node-disjoint paths. The Route Reply (RREP) messages are transmitted back to the source node via the chosen paths.

RREQ Propagation : RREQ messages in SEMR are modified from previous RREQ messages in AODV or DSR, by adding flow and congestion fields (See Fig. 4). Flow and congestion fields are used to calculate PC as a path metric. The source node initializes the flow field transmitting data size and congestion field to zero, when creating RREQ messages. When RREQs arrive in intermediate nodes, the flow value in RREQs is saved in the Congestion Cache. The congestion value in RREQ is updated by the flow value in the Congestion Cache (Refer Eq. (1)). SEMR does not use the Route Cache for various paths, similar to SMR. The Congestion Cache in Fig. 5 is created in each node in order to save NC temporarily. Every node, temporarily preserves RREQ information in the Congestion Cache. Intermediate node store the source node address, destination address, sequence number, arrival time, and flow value in the RREQ, in Src Addr, Dest Addr, Seq., and Flow field, respectively.

Previous RREQ Format	Flow	Congestion

Fig. 4. Modified RREQ message

Src Addr	Dest Addr	Seq.	Time	Flow	Check

Fig. 5. Congestion Cache

Finally, if each node receives a RREP as a reply from RREQ, the Check field is set as TRUE, otherwise it is set as FALSE. In the case the check field is set as TRUE, the data is transmited through a correspondent node because the destination node selects a path that includes the correspondent node. In addition, in the case it is set as FALSE, although RREQ is not received currently, it can be assumed that data, having flow size, will be transmitted. In addition, SEMR uses RREP_TIME_OUT to maintain the Congestion Cache. If an intermediate node does not receive a RREP during RREP_TIME_OUT, it regarded as not selecting the correct path belonging to the node. Data is deleted if the check field has a value of FALSE.

For example, suppose that the source will transmit 512 bytes of data to the destination node. First, the source node RREQ flow and congestion fields are initialized to 512 and zero, respectively. The RREQ is flooded into neighboring nodes. If a neighboring node is already received as containing an identical RREQ, it discards RREQ. RREQ information is preserved in the Congestion Cache. At this point, the check field is set to FALSE. In addition, if the same RREQ data already exists in the Congestion Cache, the neighboring node does not preserve the Congestion Cache and simply floods RREQ into other neighboring nodes. Finally, NC is calculated by summing all flow values in the Congestion Cache. NC is accumulated into the congestion field in the RREQ, and the RREQ is flooded into neighboring nodes. Therefore, a congestion value in RREQ is the PC, which is the accumulated NC. The destination can then select a path with the lowest PC.

Path Selection Method : In SEMR, the destination selects two paths. The destination waits a certain duration of time for another RREQ. The destination selects the first path that contains the lowest PC. If one or more paths containing the same PC exists, the destination selects the path arriving earlier. Then, the second path is selected as a maximally node-disjoint path of the first path. If there are two or more paths that are maximally node-disjoint with the first path, the path with the shortest hop count is chosen. If there are still multiple paths meeting the condition, the quickest path delivering the RREQ to the destination is selected. The destination then transmits RREP to the source via first and second paths selected.

Previous RREP Format	Seq.

Fig. 6. Modified RREP message

SEMR also modifies the previous RREP message by adding the Seq. field (See Fig. 6). RREP is transmitted to the source via the source routing path. When RREP arrives in the intermediate node, the intermediate node updates the check field of the Congestion Cache. If RREP arrives during RREP_TIME_OUT, the check field is updated from FALSE to TRUE. This means that the path which the node belongs to is selected by the destination.

3.3 Path Maintenance

SEMR selects the second path that is maximally node-disjoint with the first path. The term, node-disjoint, means that, if possible, overlapping nodes with previous paths are avoided. In other words, although the path cannot be used because of node mobility, collision, or power consumption, it is possible to transmit data using another path. Therefore, if one path is broken, SEMR attempts to find another path. If another path exists, data is transmitted. In the event that all paths are broken, path re-configuration is executed. In addition, when a node receives a ROUTE ERROR (RERR) message, the data field in Congestion Cache that includes RERR information is deleted in order to reduce NC. The RREQ can be supported by the Congestion Cache, which is updated periodically. It is possible to estimate congestion not only at the current time, but also at a future time, by using the reliable congestion path metric. From a traffic allocation point of view, the simple per-packet round robin scheme is used. It is possible to find the most effective traffic allocation scheme, however this is out of the scope of this paper.

4 Performance Evaluation

The simulation modules are implemented in the Global Mobile Simulation (GloMoSim) library [11]. The simulation modeled a network of 30 mobile nodes placed randomly within a 300 meter × 300 meter area. Each node has a radio propagation range of 75 meters and the channel capacity was 2Mbps. Each run is executed over 300 seconds of simulation time. A free space propagation model with a threshold cutoff [12] was used in the experiments. In the radio model, it is assumed that the ability of a radio can lock onto a sufficiently strong signal in the presence of interfering signals. The IEEE 802.11 Distributed Coordination Function (DCF) [13] is sued as a medium access control protocol. A traffic generator was developed to simulate constant bit rate sources. Ten data sessions were created, and the sources and destinations were randomly selected with uniform probabilities. The size of the data payload was 512 bytes. The random waypoint model [2] was used as the mobility model. Various mobility degrees were generate using different pause times. The minimum and the maximum speed were set to zero and 10 m/s, respectively.

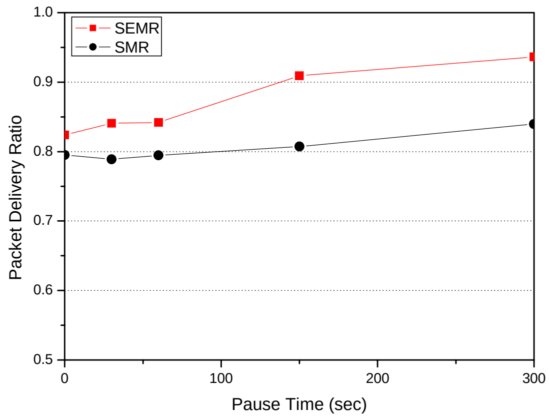

Fig. 7. Throughput

High node-density and high-mobility are considered in the simulation. The simulation compares performance of SEMR (using the least congestion path metric and two multipath) with SMR (using the shortest delay path metric and two multipath). The performance factors are throughput and end-to-end delay.

Fig. 7 presents the throughput of each protocol in the packet delivery fraction. The packet delivery ratio is obtained through dividing the number of data packets that correctly received by the destinations, by the number of data packets of the originating sources. Because SMR uses the shortest delay path metric, many congestion nodes are generated. It is confirmed that the throughput of SMR is lower than SEMR.

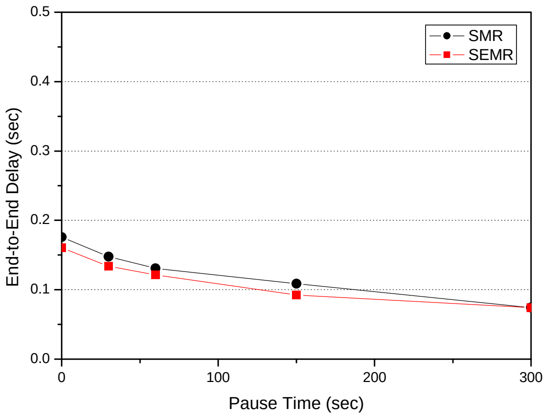

Fig. 8. End-to-end delay

Fig. 8 presents the end-to-end delay. SEMR has the shorter end-to-end delay than SMR, because it simultaneously considers both node mobility and congestion.

5 Conclusion

The Split Equal-cost Multipath Routing (SEMR) protocol is presented for highly node-densed MANETs. SEMR is an on-demand and an equal-cost multipath routing protocol that uses a congestion path metric. The congestion path metric is used to enable the possibility of estimating node congestion in current and future periods. In addition, it selects two paths for considering mobility of nodes. The performance is similar to SMR in the worst case, because SEMR is based on SMR. In a highly node-densed network, SEMR demonstrates superior throughput and end-to-end delay over SMR. In addition, load balancing and fault-tolerance problems can be much more relieved than existing SMR when the multipath routing protocol with a new congestion metric is available in the proposed SEMR.

However, there are some points to discuss for further enhancement. In perfect solution of congestion path, the combined path metric is required in order to consider both proposed congestion metric and available link capacity of the link layer. The issue of how to decide the effective traffic allocation scheme still remains. The scheduling scheme that disperses traffic is an important topic in multipath routing. In future work, the cross-layer approach in multipath routing using multiple path metrics will be evaluated. For example, the user profile in the application layer, and environment of network or channel condition, will be used, adapted for QoS routing.

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