Research Review of Development of Novel Routing Algorithms for Mobile Ad-hoc Networks

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ABSTRACT: *Routing in mobile adhoc networks is always an issue of great significance and key focus of researchers from last decade. The design of legacy routing protocols was simpler due to little dependency of applications on routing algorithms. However the large scale inception of mobile devices in market drives application developers to develop many novel applications. The applications require high processing speeds, larger memory, more battery power and high utilization of bandwidth. These applications on one hand created challenges for hardware designers to design fast and efficient processors and other entities and on the other hand challenged network engineers to research newer routing algorithms which satisfy the needs of these applications. In this paper we investigate various routing algorithms proposed for MANETs and the inherent problems which drive the development of these schemes.*

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1. Introduction

Mobile Ad-hoc Networks (MANETs) usually characterized as multi hop, self-configuring, selfadministering, are distributed systems that comprises of wireless devices (e.g. laptops, notebooks, tablets, PDAs and smart phones) which are linked together in arbitrary fashion on totally ad-hoc basis.

These networks were initially proposed for battlefield networks and disaster recovery applications due to their quick deployment feature and no need for any existing infrastructure. But with the large scale inception of mobile devices in the market, MANETs are now considered as a major stakeholder in the next generation network technologies.

Today the smartphones are available with more powerful processors than an Intel's Pentium 4 processor and higher memory. These high processing capabilities attract the common man to get a smart phone while on the other hand the software developers are introducing evolutionary applications for these handsets. Online gaming is a new trend in this area.

Some common applications of MANETs are patient monitoring, airplane exhaustion breakage supervision, cyclone evolution analysis, detection of earthquakes, remote landscapes monitoring, ecological danger detection, and providing security at public buildings, tracking enemy movement, locating an object and interactive museums or toys [1].

To facilitate these applications on MANETs, the network engineers are facing challenges to overcome the shortcomings in the MANET technology. Unlike the standard Internet, the MANETs are highly unpredictable networks. In MANET nodes move on the fly in random fashion and thus the topology of the network is always changing. The dynamic nature of the MANET topology requires routing protocols to be more flexible, robust and capable of quick convergence to adopt the changing topology. Apart from that this, the mobile nodes are battery powered hence routing protocol should be energy efficient. This paper focuses on the technological advancements in routing protocols to support multimedia applications and services. The multimedia applications usually based on 2V (Voice and Video) require some quality of service guarantees from the network entities.

2. Quality of Service Routing

The legacy routing protocols were designed for MANET considering the normal data traffic transmission over them. But when many newer applications and services were deployed on MANETs, then the performance of these protocols degraded enormously and need for optimization of these protocols attracted research community to present novel approaches for next phase of MANET routing.

According to ITU-T, QoS is defined as "*The collective effort of service performance which determines the degree of satisfaction of a user of a service*" [CCITT Rec. E.800]. In the case of multimedia applications the three parameters which can never be compromised are throughput, delay, and jitter. The standard QoS architecture has three components, the QoS Model, QoS Signaling and QoS Routing.

The first component for QoS provision in MANET is the QoS signaling protocol, called INSIGNIA [Ahn et al. 1998]. The protocol is based on RSVP and in-band signaling techniques. The limitation of INSIGNIA [2] is that it defines only two classes of traffic, best effort (BE) and real time (RT).

The second component is QoS model for MANETs. The FQMM (Flexible QoS Model for MANETs) [3] was proposed by Xiao et al in 2000. The model was a combination of the two popular IP QoS models, the IntServ model and DiffServ model.

The third component, the QoS routing can play the most significant role in this aspect, and the decoupling of routing from QoS provisioning can reduce the likelihood of meeting the QoS requirements of a particular service/application. [4] Efficient routing techniques can improve the overall performance of the network because it covers the overall state of the network. By selecting efficient routes for data transmission, the three said parameters (throughput, delay and jitter) can be improved globally.

Due to the significance of QoS routing, a lot of research in this area has been conducted to get the optimum results. These works from the research community can be divided into two main portions:

(1) Optimization of existing routing protocols and

(2) Development of new routing protocols

Research in both areas was continued from last decade in parallel and remarkable achievements were made. The following section presents an overview of major research work in the two mentioned areas which goal is to provide QoS enhancements for multimedia applications.

3. Optimization of Existing Protocols

The optimization of a routing protocol is a complex mechanism because when improving the performance, one always has to deal with several tradeoffs between several parameters. It's also a fact that a protocol can never be best in all aspects. As an example, when one want to reduce delay, the complexity and overhead of the protocol increases because extra mechanisms for delay reduction are to be implemented. Thus to modify an existing protocol, one should have to keep one eye on his target parameters to be achieved while other eye on those parameters that might change adversely and degrade the performance in one or other way.

Routing in MANET is also a tedious task because in standard Internet routing, routers are standalone devices specially designed for routing while in MANET the ordinary node have to do the same task. There is no guarantee of the intermediate node's processing capability and that of the other nodes beyond this node on the routing path. Moreover for the optimization of routing protocols, the principal objective is the minimization of routing updates for it consumes bandwidth resources [5] and this is a baseline for optimizing proactive routing protocols.

The legacy routing protocols are AODV [6], DSDV [7], DSR [8], OLSR [9] and TORA [10]. These protocols can be divided into three main types, proactive (table-driven), reactive (ondemand) and hybrid protocols.

The **proactive routing protocols** maintain routes to all nodes in the network. Each node saves routes to all destinations in a routing table. The drawback of reactive routing is their high bandwidth consumption because the nodes share routing information periodically. The performance is further degraded when the routes are broken and the topology is changed, because new routes are determined even there is no ongoing transmission using these routes. The advantage is that the routes are quickly determined and session is established. Examples of such protocols are DSDV [7], B.A.T.M.A.N [11] and OLSR [12].

The **reactive routing protocols** use flooding technique to find the routes, however the route is determined when it is needed. The reactive routing have relatively better performance as compared to proactive routing. [28] The disadvantages of this approach are high latency in route discovery process. The performance can be further degraded if the network is highly dynamic and extra-large (e.g. more than 200 nodes). Examples of reactive routing protocols include AODV [6], DSR [8], TORA [10] and LAR [13].

The third category of routing protocols is **hybrid routing protocols**, which combines the features of both proactive and reactive routing protocols. These protocols can adjust its routing strategy according to the network strategy. The drawback of these protocols is their complexity due to the dynamic topology and characteristics of MANET. Examples of these protocols are ZRP [14], HWMP [15]. HWMP is implemented in IEEE 802.11s mesh networks.

Some new classes of routing protocols introduced recently are hierarchical routing and position based routing.

Hierarchical routing divided network in clusters to increase scalability of the MANET. Examples include CBRP [16] and CEDAR. [17]

Position based routing techniques were introduces to overcome the drawbacks of topological based routing. These protocols take routing decision on the basis of node's current position in the network space. The information about the node's position is acquired by GPS. Examples of these protocols are DREAM [18] and GLS [19].

Research done on the optimization of above mentioned classes of routing protocols can be characterized into two main areas based on two different approaches.

The first approach is **Single layer optimization** which refers to the techniques of protocol optimization while being in the layered boundaries as imposed by the OSI reference model. Such types of techniques are effective well in wired networks and it's easier to implement them. The approach is not widely practiced by researchers due to its various limitations.

The second approach called **Cross layer optimization** comprises of all those techniques which violate the standard OSI layered architecture which is a baseline for protocol development in fixed Internet.

4. Cross Layer Optimization

Researchers practicing these techniques believe that the layered architecture was originally designed for wired Internet or alternatively it fits in the fixed Internet well and is not suitable for wireless networks. The paper [20] presents the example of TCP transmission mechanisms as an argument for the need of cross layer design. The IETF draft [21] defines cross layer techniques as Inter Layer Interaction and states interaction between various layers.

By violating the layered boundaries different layers can share various parameters with each other to improve the performance of a protocol on a particular layer. The violation of layered architecture is a sensitive process and one has to be very cautious when implementing some cross layer mechanism.

The paper [22] explains the cross layer design approaches and the possible threats which are to be considered before implementing any such technique.

In the paper [23] the standard routing metric is altered, using cross layer design. The new metric now accounts delay associated with packet transmissions on each node along the routing path. The delay includes queuing and contention delay while propagation and transmission delay is neglected. The values are calculated at MAC layer and used at routing layer using cross layer feedback. The feedback is implemented at route discovery stage of DSR operation and thus aiding the selection of routes having minimum delay associated.

The CLAODV [24] is the optimized version of the standard AODV protocol. The protocol is an attempt to reduce the overhead in the AODV protocol which is the main drawback of AODV. CLAODV used modified HELLO messages to be sent with no content so to reduce overhead. The AODV sequence number (SN) is transferred to MAC layer and saved there. When the sequence number is changed on routing layer, it is also updated on MAC layer. The sequence number is shared at MAC layer between neighbor nodes in the frame. At the same time the MAC address is also stored in the routing table at routing layer. Thus by routing and MAC layers are synchronized and at the end the control of HELLO messages are transferred to MAC layer. By giving the control to MAC, the HELLO messages are sent with same HELLO_INTERVAL to its neighbors only and thus reducing overhead. Simulation was done in OPNET that shows some performance improvement as compared to classic AODV.

The research in [25] proposes an alternate scheme to optimize AODV using interaction between MAC and Physical layer to provide services to routing layer. According to the author, the MAC layer when receives packets from routing layer, it saves control information (HELLO, RREQ, RREP and RRER) in one queue which he called C-queue and the data packets in another queue called D-queue. He suggests a strategy to ensure the reliable and guaranteed transmission of control information by exploiting MIMO technique. By associating a separate antenna element from the array of antenna with the C-queue, the control information will be directly transmitted without any hindrance and interruption from data traffic. If there is no control information, all antenna elements will be used for data.

Another reactive routing protocol is DSR which uses source routing approach. DSR also use route cache to maintain a list of all previously known routes for any destination in the network. However the protocol has several disadvantages including the source route itself which increases header size thus causing bandwidth wastage in large networks, flooding of route request, caching of routes which are now invalid due to topology change etc… Besides all these a big shortcoming in many routing protocols including DSR is their defaults metric i.e. hop count.

[26] is an attempt to change the conventional routing metric of DSR and select the path with least routing delay. To do so, each node calculates the delay information during the route discovery procedure and updates this value in the RREQ packet. The destination node receiving RREQ packets via different paths calculate accumulative delay associated with paths and update it in the RREP packet and send to the source.

The source save all the routes in its cache and select the one with least delay for immediate transmission and the rest for back up. The simulation results support the scheme.

The DSPA protocol in [27] use a similar approach to consider MAC delay in routing decision, additionally implementing power saving mechanism.

5. Development of New Protocols

The optimization of existing protocols for MANET using cross layer design has still some limitations, i.e. the protocol's operations are inter-related. If one modify a particular component, another component might change that has a reverse effect on the protocol's performance. It is also notable that some parts f the protocols are mandatory and can't be modify. However when developing a new protocol from scratch, the developer has a free hand on every part of design. This section explains some example protocols created recently for QoS routing.

The paper [28] suggests significant guidelines for protocol development in MANET area and emphasize on the importance of a more realistic Physical layer design for routing protocols. The classic routing protocols used the default hop count metric which is based on Distributed Bellman-Ford algorithm [29-1]. AODV, DSR, DSDV all use similar approach for route selection. The main problem with the DBF algorithm is its overhead and bandwidth consumption which is never desirable. Hence to facilitate the future applications, new protocols were being designed using different approaches and routing strategies.

The *first approach* in this area was to change the DBM algorithm with more efficient and bandwidth saving mechanism. The OLSR [9] protocol is a proactive protocol and just like others share routing information using HELLO and Topology Control (TC) messages but the flooding is reduced using Multi Point Relays (MPR) algorithm.

The *second approach* in this area was to combine the proactive and reactive techniques to design protocol to eliminate the shortcomings of both, i.e. the high bandwidth consumption in proactive protocols and the high route discovery delay in reactive protocols. An example of such approach is the ZRP protocol [14]. It defines zones for each node, consisting of neighbors of the node. A node has only routes to all nodes in its zone and not to all nodes in MANET. Thus routing updates are sent only to nodes in its zone area. If the destination node is not present inside the zone, it invokes reactive approach to find route to the remote destination. Thus the protocol behaves as proactive inside zone and becomes reactive out of the destination.

The *third approach* which gained much popularity is the Hierarchical routing. The network in this approach is divided into clusters. CEDAR [17] is such a protocol which establishes a network core. The core nodes receive information of all stable routes from the nodes while information about the dynamic and unstable nodes is kept locally on nodes. The link information are usually computed on MAC layer and are propagated to core. The core establishes the path on the basis of link states between source and destination. The protocol potentially reduces bandwidth consumption.

The *fourth approach* is the geographical or position based routing. [18] Presents a detailed description of position-based routing protocols. The leading protocol in this area is DREAM. [18] The source node using this protocol selects routes to other nodes on the basis of destination node's position. The position information of all neighbors is kept by each node. DREAM uses restricted directional flooding of ontrol packets. The frequency of sending these packets is dependent on source node's speed. The directional flooding of control packets improves performance in terms of route discovery. DRP [29] is another popular implementation of position based routing. DRP is inspired from the legacy DSR protocol and implements directional routing and neighbor's tables. The protocol is implemented on top of MDA (MAC protocol for directional antennas) and tested. The performance metrics including packet delivery ratio, end to end packet delay, and routing delay, were tested. The results were compared with that of DSR. The comparison shows that DRP outperform DSR in all respects.

Another *class of novel routing* algorithm is anonymous routing in which a node does not express his current location and still use location based routing. ALARM [30], is a new algorithm recently proposed by Defrawy and Tsudik. The goal of the scheme is to ensure privacy in location aided routing using advanced cryptographic techniques such as group signatures. The protocol uses location information of the nodes to construct network topology and forward transmissions while maintaining node authentication, data integrity, anonymity of nodes, and traceability. The link state routing protocol (OLSR) is selected as best fit to implement the algorithm because OLSR obviate need for route discovery and inherited support for security.

ALERT [31] is an algorithm suggested by Shen and Zhao in the same category to overcome the short comings of location aided routing [[32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43]]. ALERT "*provides high anonymity protection (for sources, destination, and route) with low cost*". [31] The protocol dynamically divides network topology into zones and then randomly select nodes from each zone as relay nodes. The protocol uses GPSR [44] to forward packets to relay nodes until the packet is sent to destination zone where the relay node send the packet to its original destination. To ensure anonymity, the protocol uses dynamic pseudonym instead of original MAC addresses. Hash function SHA-1 is used to avoid collision of pseudonyms. The routing algorithm divides network into zones each having *k* nodes. The destination node called *D* resides inside Destination zone "D_z". The zone partitioning is hierarchical and executed by data source. The source also selects a relay node in each zone which it calls "*RF*" (Random Forwarder). The traffic from source to nearest RF is routed via GPSR algorithm. The data is finally broadcasted to destination zone "D_z" having "*k*" nodes, hence achieving k-anonymity. The use of destination zone is to ensure anonymity of destination which may be desired. To ensure source anonymity a mechanism called "*notify and go*" is implemented. The dynamic and randomness in RF selection aides route anonymity. The protocol is also resilient to timing and intersection attacks.

*Medium aware routin*g is a very popular cross layer design approach for the provision of QoS in routing protocols. The MAC layer is the one which provide services directly to Routing layer. The MAC contains link information which is invisible to routing protocol. The IETF draft [21] describes the interaction between MAC and routing layer. The useful parameters on MAC layer are SNR, Interference, Congestion, Bandwidth, link type and link delay information. The LBRP protocol [45] presents a reliable routing scheme based on link availability prediction by mutual cooperation of MAC and routing layers.

The energy aware routing algorithm is suggested. [46] The protocol assumes that all nodes are aware of its residual energy and support dual channels i.e. separate channels for data and control. To start the routing process, the source node broadcast a wake up signal using control channel. Every node receiving this signal will open their data channels and come to fully active state. Next the source node will broadcast GREQ (Graph Request) message over the data channels which are now opened. Every node receiving GREQ will respond with GREP (Graph Reply) message. The GREP message contains node's residual energy. The global topology of the network is obtained using BFS (Breadth First Search). The cost of each node is calculated:

$$A = (100 - P_{down}) / S$$
$$B = (P_n - P_{down})$$
$$\text{Cost} = S - (B / A)$$

Where P_{down} is set to 15%, P_n is the node's residual energy received via GREP, while S is a scaling factor. Then the least cost path is find out using Dijkstra algorithm. Then the source node broadcast a RFP (Route Finalize Packet) packet to all nodes no to shut down their data channels till they receive "*Sleep*" message from the source.

6. Conclusions

The paper presents a comprehensive sketch of major research work conducted in the field of mobile ad-hoc networks for provision of quality of service which is required by various applications deployed in these networks. The paper is organized to categorize the recent research to give readers a clear understanding of the research area and develop one's interest to think beyond the conducted research.

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