An Optimized OSPF Routing Protocol for Mobile Ad-hoc Networks

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Abstract—In this paper, we propose an Optimized OSPF (Open Shortest Path First) protocol for MANETs (Mobile Ad-hoc Networks). MANETs are multi-hop ad-hoc wireless networks where nodes can move arbitrarily in the topology. The network has no given infrastructure and can be set up quickly in any environment. Traditional OSPF is not also well used in multi-hop wireless networks. The optimized OSPF we proposed in this paper is a routing protocol which is more efficient for such mobile ad hoc networks. This paper describes and designs an optimized routing protocol for MANET referring to certain extensions to OSPF for MANET and OLSR routing protocol. The path selection optimization scheme we propose is aiming at reducing the number of redundant retransmissions while diffusing a broadcast message in the network and reducing overall overhead of control traffic. In conclusion, the optimized OSPF protocol improves the performance when using in MANETs as the experiment results show.

Index Terms—Routing Protocols, OSPF, MANET, Wireless, Optimization

I. INTRODUCTION

The use of Mobile Ad hoc Networks (MANETs) is critically important in situations where mobile nodes are required to communicate with each other without relying on any fixed infrastructure, such as access points.

Mobile Ad-hoc Networks (MANETs) are composed of mobile nodes mainly characterized by the absence of any centralized coordination or fixed infrastructure, which makes any node in the network act as a potential router. MANETs are also characterized by a dynamic, random and rapidly changing topology. These make the classical routing algorithms fail to perform correctly, since they are not robust enough to accommodate such a changing environment. Consequently, more and more research is conducted to find more optimal protocols. As a result of such efforts, different routing protocols have been designed for MANET operation, the most prominent to date including the OLSR (Optimized Link State Routing [2]) and AODV (Ad hoc On Demand Distance Vector[3]).

OLSR is based on a proactive link state approach. One question then immediately comes to mind: if OSPF and OLSR are so similar, why is OSPF not also used on multi-hop wireless networks? Operating OSPF on this new type of network is indeed a seducing idea for at least two reasons: firstly, OSPF is extremely well deployed, known, and renowned, thus facilitating greatly the integration of multi-hop wireless networking in the existing infrastructure, and secondly, seamless unification of wired and wireless IP networking under a single routing solution: an interesting perspective in terms of flexibility, maintenance, and costs. There are in fact multiple issues with the use of OSPF in ad-hoc networks [4][5]. The main problem is the amount of overhead necessary for OSPF to function, which is too substantial for the low bandwidth available so far on multi-hop wireless networks.

However, OSPF has a modular design, using different modules called interface types, each tailored for specific technologies, such as Ethernet (Broadcast interface type), or Frame Relay (Point-to-Multipoint interface type). According to the modular characteristic of OSPF, we can propose a design as an extension of OSPF, namely a new OSPF interface type for mobile ad-hoc wireless networks. The goal is to let the OSPF adapts well to the characteristics of mobile ad-hoc wireless networks. This paper applies many of the principles and concepts learned through prior work to OSPFv3, along with new concepts based on current requirements. In the paper, we describe extensions to OSPF to support mobile ad hoc networks (MANETs). The extensions include an OSPF-MANET interface, a simple technique to reduce the size of Hello packets by only transmitting incremental state changes, and a method for optimized flooding of routing updates.

II. RELATED WORK
In the recent years, research efforts have been focusing on improving the performance of routing protocols in MANET. The Internet Engineering Task Force (IETF) created a MANET working group (WG) to deal with issues related to the complexity of constructing MANET routing protocols. The MANET WG coordinates the development of several candidates among the protocols including OLSR and AODV[6]. These protocols are classified into two classes based on the time when routing information is updated, the Proactive Routing Protocols (PRP) and Reactive Routing Protocols (RRP). The WG may also consider a converged approach such as hybrid routing protocols. There are other classifications of routing protocols such as the distance vector (DV) class and link state (LS) class based on the content of the routing table. The DV protocols broadcast a list (vector) of distances to the destinations and each node maintains the routing table of the shortest paths to each known destination[7]. On the other hand, the LS protocols maintain the topology of the network (links state). Each entry in LS routing table represents a known link. In LS routing, each node needs to calculate the routing table based on the local (links state) information in order to obtain a route to destination. Normally, the link state protocols are more stable and robust but much more complex than distance vector protocols. There are also instances of the above two family in MANET. The OLSR is the most widely used link state protocol, while AODV is the most popular distance vector protocol. General analysis of link state routing and distance vector routing in MANET respectively are provides in [8] and [9] respectively.

Another classification of routing protocols is source routing and hop-by-hop routing. In source routing, the source computes the complete path towards the destination, which consequently leads to loop-free routing. In hop-by-hop routing, each intermediate node computes the next hop itself. The nature of hop-by-hop routing reduces the chance of failed route in MANET, which suffers much faster topology changes than wired networks. Consequently, the source routing protocol in MANET, DSR, allows the intermediate nodes and even overhearing nodes to modify the route in order to adapt to the nature of MANET. Most MANET routing protocols such as OLSR and AODV have the hop-by-hop nature.

Besides the above traditional categories, the Relay Node Set(RNS) [10] framework is introduced to analyze the ad hoc routing protocols. According to [10], most ad hoc routing protocols including OLSR, AODV and TBRPF can be analyzed within the framework. OLSR aims at being completely independent of the underlying link-layer being used. Thus, even though OLSR might utilize information available from an underlying link-layer, characterizing the existence and quality of the links, the protocol specifies mechanisms for neighbor sensing, including the ability to detect the link “characteristics” (in terms of symmetry or asymmetry as described above).

III. OSPF MANET INTERFACE DESIGN AND SPECIFICATION

MANET routing protocols are responsible for creating routes in a dynamically changing network with low bandwidth, low power and resource constrained computing nodes. To achieve these goals, an optimized MANET routing protocols are designed with the following primary expectations:

1. Provide stable loop free connectivity.
2. Have reduced control overhead.
3. Respond to dynamic changes in node mobility.
4. Have scalability and distributed routing.
5. Support QoS traffic prioritization.
6. Provide secure routing.

We analysis that the key challenge with routing on multi-hop wireless networks in the OSPF context: drastic control signaling reduction while keeping track of a topology changing much more often compared to Internet topology. Accordingly, OSPF specifications for MANET are different from the wired networks. They have the following built-in principles[5]:

Principle 1: User data is always forwarded over optimal paths.

Principle 2. User data is only forwarded over links between routers with explicitly synchronized link state data-base.

According to the principles and expectations referred above, we propose the MANET interface model and specifications for OSPF protocol. The core and auxiliary protocol components are shown in Table 1.

Table 1 specifies the component of the core and auxiliary functionality of OSPF. All the components are desired to support the protocol running in a MANET network. The general functionalities of these components are interpreted as follows. Specially, Neighbor Discover and MPR(Multi-Point Relay) Selection will be detailed, as the optimization scheme is aimed at improving them.

A. Packet Format and Forwarding

An universal specification of the packet format and an optimized flooding mechanism serves as the transport mechanism for all control traffic.

B. Neighbor Discover

Optimized OSPF aims at being completely independent of the underlying link-layer being used. Thus, even though optimized OSPF might utilize information availa-
ble from an underlying link-layer, characterizing the existence and quality of the links, the protocol specifies mechanisms for neighbor sensing, including the ability to detect the link “characteristics” (in terms of symmetry or asymmetry as described above).

In optimized OSPF, a node emits HELLO-messages periodically. Changes in the neighborhood are detected from the information in these messages. A HELLO-message contains the emitting node’s own address and the list of neighbors known to the node, including the status of the link to each neighbor (e.g. symmetric or asymmetric). A node thereby informs its neighbors with which neighbors, and in what direction, communication has been confirmed.

Upon receiving a HELLO-message, a node can thus gather information describing its neighborhood and two-hop neighborhood, as well as detect the “quality” of the links in its neighbor hood: the link from a node A to a neighbor B is symmetric if in the HELLO-message from B the node A sees its own address (with any link status) otherwise the link is asymmetric. Each node maintains an information set, describing the neighbors and the two-hop neighbors. Such information is considered valid for a limited period of time, and must be refreshed periodically to remain valid. Expired information is purged from the neighbor and two-hop neighbor sets.

Fig.1 shows the procedure of a typical neighbor discovery session using HELLO messages.

![Figure 1. Typical neighbor discovery session using HELLO messages.](image)

**Figure 1. Typical neighbor discovery session using HELLO messages.**

The state machine of a basic implementation of neighbor discover is provided as Fig.2. An implementation may use some heuristics (Step (3) below), beyond the SPT reachability, to decide whether or not it considers a new adjacency to be of value.

**C. MPR Selection and MPR Signaling**

The objective of MPR(Multi-Point Relay) selection is for a node to select a subnet of its neighbors such that a broadcast message, retransmitted by these selected neighbors, will be received by all nodes 2 hops away. The MPR set of a node is computed such that it, for each interface, satisfies this condition. The information required to perform this calculation is acquired through the periodic exchange of HELLO messages.

**D. Topology Control Message Diffusion**

Topology Control messages are diffused with the purpose of providing each node in the network with sufficient link-state information to allow route calculation.

**E. Route calculation**

Given the link state information acquired through periodic message exchange, as well as the interface configuration of the nodes, the routing table for each node can be computed.

The Optimized OSPF core feature set provides functionality to discover the neighborhood of a node and to efficiently flooding information to the MANET through the concept of MPRs. Using only these features a MANET is provided with the ability to have accurate routing information on nodes participating in the Optimized OSPF domain. In most usage scenarios it is intended to have nodes communicate with the outside world, mostly the internet.

**IV. PATH SELECTION OPTIMIZATION.**
A. Flooding optimization

Flooding, in its simplest form, means that all nodes retransmit received packets. To avoid loops, a sequence number is usually carried in such packets. This sequence number is registered by receiving nodes to assure that a packet is only retransmitted once. If a node receives a packet with a sequence number lower or equal to the last registered retransmitted packet from the sender, the packet is not retransmitted. On wired networks, other optimizations are usually added such as no retransmission on the interface at which a packet arrived.

On a wireless multi-hop network, however, it is essential that nodes retransmits packets on the same interface that it arrived, since this is the very nature of wireless multi-hop networks. This again causes every retransmitter to actually receive a duplicate packet from every symmetric neighbor that retransmits the packet. A wireless flooding scenario is depicted in Fig. 3. One can see that every transmission leads to a reception of the same packet. The originator of the flood could be any node in the Fig 3. The number of retransmissions using traditional flooding is n-1 where n is the number of nodes in the network. In our case(see Fig. 4) it will be 18. This flooding technique can clearly benefit from some sort of optimization, but still ensuring that each node in the network receives a flooded packet at least once, thus saving valuable bandwidth. Multi-Point Relay (MPR) is one of the most popular optimization, having each node select a minimal set of "relay nodes", responsible for relaying flooded packets as shown in Fig.4. From the local point of view of a node, flooding a packet to the center node, this corresponds to only a small number of "necessary" neighbors relaying the broadcast.

In addition to ensuring that the number of repeaters is drastically reduced, while flooding still covers each node in the network, MPRs have another interesting property in the context of link state routing. Sole knowledge of the links from each node to its neighbors for which it is "necessary" is sufficient in order to compute the shortest paths network-wide, as if the knowledge of every link in the network was available. This property thus enables a drastic reduction in the amount of link state that needs to be signaled, while still ensuring optimal connectivity.

B. Adjacency Selection Optimization

The MPR set of node S consists of all the MPRs of S, and the nodes in the set satisfy the conditions following:

1. Any node in MPR set is an 1 hop neighbor of node S.
2. By the nodes in MPR set, S can send messages to all its 2 hop neighbors.

As only the MPR nodes are in charge of forwarding TC messages, it is obvious that the less the number of MPRs is, the smaller the flooding of TC messages would be. So, without considering other factors, a MPR set is more excellent when it has less nodes, and this is helpful for the saving of resource. [20] proposes one heuristic for the MPR selecting, using greedy algorithm, which is treated as the standard way of selecting MPRs. Each node...
has its MPR set and will broadcast its MPR information in the periodic update packets. When propagating the periodic update packets, only the MPRs forward update packets. We use the heuristic algorithm proposed for the protocol to compute the MPR with slight adaptation. The following definitions are given first.

\( N \): represents the subset of neighbors of the current node.

\( N_2 \): represents the set of two-hop neighbors of the current node.

\( D(y) \): represents the degree of a one-hop neighbor node \( y \) (where \( y \) is a member of \( N \)). It is defined as the number of symmetric neighbors of node \( y \), excluding all the members of \( N \) and excluding the node performing the computation. The flowchart given in Fig. 5 summarizes the essence of the adapted version of the heuristic algorithm proposed in [22].

Select all the 1 hop neighbors that could provide only reachability to some 2 hop neighbors as MPRs. Then, if there are still some 2 hop neighbors that are not covered by MPRs, select the 1 hop neighbors who could cover the most uncovered 2 hop neighbors as MPRs. Repeat this step until all the 2 hop neighbors are covered by MPRs.

In this paper, we used an algorithm which improves greedy algorithm from a different angle, which decreases the number of MPRs significantly.

Based on this “necessity of selecting”, we proposed NFA (Necessity First Algorithm) to select MPRs. From the name of this algorithm, it is directly shown that this algorithm selects MPRs with the consideration of necessity. The basic idea of NFA is: when there is no 1 hop neighbors with “necessity of selecting”, deleting the neighbor with poorest cover ability purposely to create “necessity of selecting”, then choosing the neighbors with “necessity of selecting” as MPRs. The statement of NFA is as following:

**Step A:** Calculate \( N, N_2, \) and \( D(y) \) of all the nodes in \( N \).

**Step B:** If there are some nodes in \( N \) who are the only nodes providing Reachability to some nodes in \( N_2 \), select them as MPRs. Then, delete all the 2 hop neighbors that are covered by these nodes from \( N_2 \).

Now:
If there isn’t any node in \( N_2 \):
NFA is over.
Else

go to step 3.

**Step C:** Recalculate \( D(y) \) of all the nodes in \( N \), choose the nodes with the minimal degree.

If there is only one node with the minimal degree:
Delete it from \( N \). Recalculate \( D(y) \) of all the nodes in \( N_2 \). Go to step 2.
Else
Using RULE 1 to break tie and delete the selected node from \( N \). Recalculate \( D(y) \) of all the nodes in \( N_2 \). Go to step 2.

**RULE 1:**

If \( D(y_1) = D(y_2) \)

then for \( y_i \) ( \( i = \{1, 2\} \)):
its probability of becoming a MPR has been deprived while other algorithms usually don’t delete 1 hop neighbors from N. When a node has been deleted, it will never become a MPR. It is just this deletion makes the creation of necessity come true, so this step is the key of the algorithm. What is more, deleting the nodes covering the minimal number of 2 hop neighbors reflects a consideration of cover ability: Every time a node with the minimal cover ability is deleted, the “necessity of selecting” is left for the nodes with stronger cover ability. As shown in Fig. 6, e and f are deleted, and the chances of becoming MPRs are left for c and d.

C. Link State Declaration Optimization

Link state routing protocols are based on nodes flooding the network with information about their local links. In protocols like ISIS[18] this information is mostly links to subnets, since these protocols are highly based on aggregation of networks. The optimized OSPF uses host based flat routing, so the link state emitted describes links to neighbor nodes. This is done using Topology Control(TC) messages. The format of a TC message is shown in Fig. 7.

TC messages are flooded using the MPR optimization. This is done on a regular interval, but TC messages are also generated immediately when changes are detected in the MPR selector set. In optimized OSPF the flooding process itself is optimized by the usage of MPRs, but the MPR technique introduces two link-state declaration optimizations as well. As we will see in the Auxiliary functionality as we referred above, OLSR nodes can also be tuned to send more than just its MPR selector set. One should notice that more robust routing could be achieved by announcing more than the MPR selector set.

The MPR functionality introduces two optimizations to TC messaging:

1. Size optimization

The size of TC messages is reduced due to the fact that a node may only declare its MPR selectors in TC messages. The factor of this reduction is related to how dense the network topology is. In a topology, the TC message size of the center node would be reduced to half the size of a “classical” TC message (not including headers). When using IPv6, a simple example like this reduces anet-wide broadcast message with 64 bytes.

2. Sender optimization

Nodes that have no links to declare usually do not transmit TC messages. The exception here is nodes that just lost their MPR selectors. These nodes are to generate empty TC messages for a given interval to update the nodes in the MANET.

But except from this special case, if only declaring MPR selectors in TC messages, only nodes selected as MPRs will generate TC messages. Such a reduction in actual transmitted messages greatly reduces the overall overhead of control traffic.

V. SIMULATIONS

We used NS-2.33 simulator to evaluate our proposed optimized protocol. The simulation scheme is designed to prove the optimization schemes we proposed for the protocol.

A. Experiment 1:

Consider the 10 to 60 sets of mobile nodes with the size of 800m X 800m. In this simulation model, the factors that have been considered are:

1. The Number of nodes: The number of nodes varies among 10 to 60 with different scenarios.
2. The number of one hop neighbors per node: In this simulation model, we set all the nodes with the same cover radius. Then, by changing this cover radius, we adjust the number of one hop neighbors per node, by which the density of nodes in the network is also controlled.

In this experiment, the number of one hop neighbors varies from 10 to 35. As the number of one hop neighbors increases, the nodes in the network become denser.

For each scenario with the number of nodes and the number of one hop neighbors, we ran the simulation for both OSPF and Optimized OSPF. The whole numbers of MPRs selected by all the nodes in the network using greedy algorithm and NFA are recorded, and the packet delivery ratio is calculated. Fig. 8 shows the simulation graph for packet delivery ratio by using OSPF and Optimized OSPF protocols with their respective algorithms.

Figure 8. Simulation graph for packet delivery ratio
B. Experiment 2:

In experiment 2, the nodes are generated randomly in the network with the size of 800m X 800m. All the nodes in experiment 2 use the OSPF protocol and optimized OSPF respectively. The only traffic in the network is the diffusion of control messages of OSPF: HELLO messages and TC messages. After the execution time, the results are recorded for all sets of mobile nodes. Fig. 9 shows the simulation graph for percentage of TC messages flooding in the network.

![Simulation graph for TC messages](image)

**Figure 9. Simulation graph for TC messages**

### VI. CONCLUSION

In this paper, we describe an optimized OSPF routing protocol for Mobile Ad-hoc NETworks (MANETs). The protocol is an optimization of the classical OSPF protocol tailored to the requirements of the MANETs. We design the protocol referred to the extension of OSPF and OLSR. The key concept used in the protocol is that of multipoint relays (MPRs). MPRs are selected nodes which forward broadcast messages during the flooding process. This technique substantially reduces the message overhead as compared to a classical flooding mechanism, where every node retransmits each message when it receives the first copy of the message. Thus, a second optimization is adjacency selection by use smart peering selection to improve the routing efficiency. This paper also proposes other optimization such as link set, link state declaration and topology reduction. Except for these optimizations, this paper put forward substantial elements of the protocol and MANET interface type. The protocol is a particularly suitable method for MANETs.

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