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An Efficient Routing Protocol for Multiple Static Sources and Multiple Mobile Sinks in WSN

Meera G S[1], Priya Sekhar S[2], Shivam Patel[3]

Department of Computer Science and Engineering, LMCST, Trivandrum, India[1, 2]

Department of Computer Science and Information Systems, BITS-Pilani KK Birla Goa Campus, Goa, India[3]

Abstract: The mobility of the sinks in the network would help to improve the lifetime of the network in many ways. Many routing protocols have been proposed for providing an efficient routing pattern in the network layer for a single sink scenario. In this paper we propose an efficient routing algorithm for routing towards multiple mobile sinks. Recent literatures have provided a protocol for routing towards a mobile sink, whose location is already known to the source in advance. But this early knowledge of the location of the mobile sink is not a feasible solution in practice. This paper proposes to use a gateway node to calculate location of the mobile sinks and hence route the data towards that sink using greedy forwarding. Steiner points are also introduced in the network as a solution for providing the routing pattern when multiple static sources are transmitting the data simultaneously. Simulation results have shown that our approach performs better than Minimum Spanning Tree (MST) and direct routing.

Keywords: Mobile WSN, Steiner Tree, Elastic Routing, Energy efficient.

I. INTRODUCTION

The proliferation of Wireless Sensor Network (WSN) in many domains has created interests in the study of it in recent times. A typical WSN consists of large number of small autonomous sensors deployed in a wide area of application domain. The sensors are usually deployed in an area where human interventions are almost impossible and hence efficient energy supply must be available throughout for a long term deployment. The main drawback with a typical sensor node is the constraint in the resources such as power, memory bandwidth etc. [1]. Each node or mote in the network is equipped with a microcontroller, a radio transceiver, a battery and so on. Since the energy powered by the batteries is very small, certain energy efficient schemes must be provided to keep the network alive. Hence energy efficient protocols must be designed in the routing layer and in the MAC layer.

Since the applications of WSN spread in vast domains like health-care, area monitoring, animal tracking, military surveillance etc.[1], the demand of efficient routing protocols to keep the network energy efficient is increasing. In a typical WSN, where all the nodes remain static, each source node monitors various physical or environmental conditions like sound, temperature, light, and pressure etc., process those sensed information and transmits them to a base station (sink) node. Energy consumption is high for a node during sensing and transmitting. In a scenario where all the nodes are static, most energy will be consumed by the node neighbouring to the sink. This will in turn affect the lifetime of the entire network.

Hence to enhance the network lifetime, one approach is to make the sink mobile, so that it would take turn to become the neighbour of each and every node, so that the energy consumption in the network can be evenly distributed. Several routing protocols have been proposed in the literature, for efficiently routing the data to such a mobile sink based network.

Among many other protocols available, elastic routing utilizing the greedy forwarding technique is considered to be efficient in terms of data delivery delay, energy consumption and control overhead. But, this is a scenario of many to one communication, which can still consume energy. If there are multiple sinks in the network, the problem of energy consumption can be further reduced, creating a many to many communication. We can deliver the data generating from different sources to different mobile nodes.

The main aim of this paper is to provide an efficient routing pattern when there are multiple static sources and multiple mobile sinks in the network. We propose to use a gateway node in the network, which will usually be located in the centroid region of the network, to whom the data from the source will initially be propagated to. The gateway node then uses localization technique for routing the data to the mobile destination. The overhearing feature proposed in [2], is also used for finally transmitting the routing information from source node to the sink.

The Steiner tree concept is also introduced in the network for routing the data, when there are multiple static sources simultaneously transmit the data. The proposed protocol has been simulated using TinyOS simulator and has been analysed that this protocol performs better in terms of energy efficiency, control overhead and packet delivery.

Section II introduces the background work in detail. Section III explains about the proposed approach, the assumptions used and the motivation behind our approach. Section IV explains the simulation results and finally Section V concludes the paper.

II. BACKGROUND

Due to the need for the survival of the network under harsh environments, mobility in WSN is gaining importance. The connectivity and coverage issues in static WSN can be overcome by introducing mobile nodes in the network. WSN offers several advantages by enabling mobility in the network such as increase in the lifetime of the network, reduction of coverage holes in the static sensor network through a process of relocation, reduction in energy consumption during communication and better targeting and monitoring.

Most of the traffic in sensor network occurs in the area near to the base station, since the nodes neighbouring to the base station are responsible for forwarding the data arriving from all other nodes. This in turn reduces the lifetime of the network and is called funnelling effect. Mobile nodes usage in the network helps to solve this issue. Hamida et al [3] suggest the use of a mobile sink which can reduce the funnelling effect and thereby increase the lifetime of the network. The concept of Data MULE, which follows a particular path and collects data from static node and then delivers the data to a base station, has been proposed in the paper [4].

However, introducing mobility in the network poses significant challenges in the network like connectivity issue, packet loss, and energy consumption and so on. Mobile WSN is defined as a network with at least one of its' component is mobile. Mobility in WSN can be classified into controlled and uncontrolled mobility. In controlled mobility, the sensor nodes move with respect to the control from the base station. In uncontrolled mobility, the objects move according to the environment conditions and they do not have any pre-defined pattern. Controlled mobility have a pre-defined pattern and they follow a specific mobility model such as random waypoint mobility model, Manhattan mobility model, gauss markov mobility model and so on [5]or move as per instructed .

In the network, the mobility can be introduced at different points. The base station, regular intermediate sensor nodes or the relay nodes can be mobile depending on various applications. Based on their role in the network, the mobile nodes are generally categorised as relocation nodes, mobile Data Collectors, mobile Sinks and mobile Relays [6]. Here we consider the mobile sink based network which has the advantage over static sink based network. As mentioned earlier, since the nodes neighbouring to the sink consume huge energy and thereby reducing the network lifetime, efficient routing protocols must be designed for routing the data from the sensed event to the mobile base station.

Several routing protocols have been proposed in the literature for routing the data from single static source to single mobile sink. Among them it has been analysed that Elastic routing [2] is more efficient than other protocols in terms of data delivery delay, control overhead and energy consumption. Elastic Routing protocol makes use of overhearing feature and greedy forwarding mechanism to route the data to the mobile sink. Many other protocols like TTDD, GRAB, ALURP, LPTD, LEACH, GBEER etc., consume high energy and cause delay in data delivery. These comparisons have been analysed in [2].

Most of these protocols are based on many-to-one or one-to-one communication paradigm. Here, these protocols are motivated towards routing the data to a single mobile sink. However, for large WSN, the need for multiple mobile sinks arises. The need for the use of multiple mobile sinks in the network arises in many situations. For instance, in environmental monitoring applications, forest rangers carry the wireless communication devices in order to collect data from sensor nodes deployed in the mountain area. In the case of military surveillance applications, moving soldiers collect information about the hostile objects deployed in the area [7].

Several routing protocols exist in the literature, for providing an optimal routing path towards multiple mobile sinks. As proposed in [8], which is a centralized routing protocol, uses traffic allocation method for routing the data to various mobile sinks. It is based on graph model for maximizing the network lifetime, which is an NP-Hard problem and uses an approximation algorithm as a solution. AVRP and TRAIL are two data gathering protocols [9], which are suitable for a distributed network. AVRP is a shortest path routing protocol, which is aimed for a dynamic mobile WSN with moderate or heavy traffic. It uses random walk technique to deliver the packet to the destination, where it selects a neighbour node randomly on its path to route the data and finally reach the destination. It initially creates a delivery structure by dynamic Voronoi scoping [9]. As a result huge delay is incurred for delivering the data. On the other hand, in the case of TRAIL protocol, the trail-based forwarding and random walk is used for routing the packet to the mobile destination. It is based on mobile WSNs with light traffic and uses anchor nodes which forward the data to the sink based on its trail information. The main objective of the TRAIL is to reduce the protocol overhead for route discovery and maintenance in dynamic mobile WSN [9].

Similar to elastic routing protocol, the feature of overhearing is used in DDRP [10], which is a data driven routing protocol. It overhears the packet information such as the known distance from the sender to the target mobile sink. Although, the overhearing functionality is used hop by hop and it could create overhead issue. In Multi-Stage Data Routing protocol or MLRP [11], Voronoi scoping and dynamic anchor selection is used for routing the data to the mobile sink. The protocol proposes to create data

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delivery structure across the network by choosing various anchor nodes. Construction of data delivery structure across the network would also impose huge performance overhead and delay. In the paper [12], the routing pattern is based on the construction of routing trees induced by information potential as the sink moves. The data will be relayed via a relay node and then routed to the destination, which causes huge delay and overhead issue, in case of multiple sinks.

Our proposed approach aims to use the feature of overhearing used in Elastic Routing [2], together with an approximation solution of Steiner Minimum Tree (SMT) problem for efficiently routing the data from multiple static sources to multiple mobile sinks. Our approach proposes to select a gateway node from the centroid of the network area and then route the data from the source node to that gateway node. The gateway node then chooses an optimum mobile base station, which is geographically closer to the source node. The overhearing feature suggested in [2] is used for finally transmitting the data from source node directly to the mobile base station.

When there are data from multiple static sources, a Steiner tree is concept is utilized for routing the data to the mobile destinations. Since there are multiple static nodes simultaneously transmitting the data in the network, a minimum path must be considered for routing the data across in minimum time. Steiner Minimum Tree problem [13], provides an efficient approach for routing the data using minimum path in minimum time. This will in turn reduce the delay in packet delivery.

III.PROPOSED APPROACH

A. Problem Statement

The network consists of N static nodes uniformly distributed in an area A, with a gateway node G, deployed in the centroid area of the network. Among the N static nodes, n nodes have data to transmit to the sink. The aim is to route the data from multiple static sources to mobile sink, among the m mobile sinks, by choosing an optimal sink closer to the source node.

B. Assumptions

We assume that the gateway node G, initially knows the location of all the mobile sinks. Also, each node knows their geographic locations. We also assume that every static node knows their neighbours.

C. Motivation

The problem of routing the data from static source to a mobile destination as proposed in [2] assumes initially that the location of the mobile sink is known to the source and it will route the data to the mobile sink using greedy forwarding. But, in most of the practical scenario, this situation is not feasible. The location of the mobile sink will not know to the source as it is changing periodically.

Hence there should be some alternative method for routing the data to the mobile sink by calculating the nearest destination closer to the source. The major steps involved in establishing the routing path between multiple static sources and multiple mobile sinks are described below.

The nodes in the network are deployed in a random manner covering a sensor network area A. It is assumed that every static node in the network know the location of their immediate neighbours. We consider a centroid region in the network of radius R and a point in the centroid region is assumed as (xc, yc), such that the area of the centroid (R2) << the sensor network area A.

The centroid region of radius R is the gateway of the network, where the gateway node resides. The choice of the gateway node is based on some election algorithm similar to the approach proposed for LEACH protocol [15]. In LEACH protocol, a selection algorithm is used for choosing the gateway node among the set of nodes available in the centroid area. Gateway nodes are chosen stochastically (randomly) as follows:

$$T(n) = \frac{P}{1 - P \times (r \, mod P^{-1})} \; \forall n \in G$$

$$T(n) = 0 \; \forall n \in G$$

Where n is a random number between zero and one

P is the gateway node probability and

G is the set of nodes that weren't gateway node in the previous rounds

The algorithm is designed such that each node becomes a gateway node at least once. Once the data from a static source reaches the gateway region of radius R, the node which first receives the data in the gateway will broadcast it to all other nodes in the gateway and finally reach the current gateway node, which has been elected based on the election algorithm.

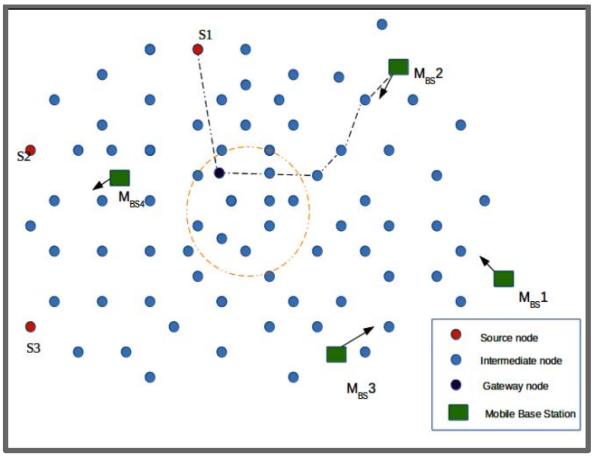

Fig 1. Scenario of single static node communicating to a mobile base station via gateway node

The mobile sinks moving around the network follow a random waypoint mobility pattern. The location of the mobile sinks is periodically updated to the gateway node through several static nodes using greedy forwarding. When static sources have data to transmit, it initially

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transmits it to the gateway region using greedy forwarding. In the gateway region, whose area is R2 will route the data to the current gateway node chosen. The gateway node having received the location of the mobile sinks periodically, will route the data to the sink, whose euclidean distance with the source is smaller.

The above scenario is depicted in figure 1. Here, S1, S2, S3 are the source nodes. MBS1, MBS2, MBS3 and MBS4 are the set of mobile sinks. The dotted circle in red is the area of centroid where the gateway node resides. The node in violet colour is currently acting as the gateway node. The source node S1 has data to transmit. It initially route the data to the gateway node in the centroid area R, using greedy forwarding and the gateway node then transmit the data to the nearest mobile destination, MBS2, which is closer to the source S1.

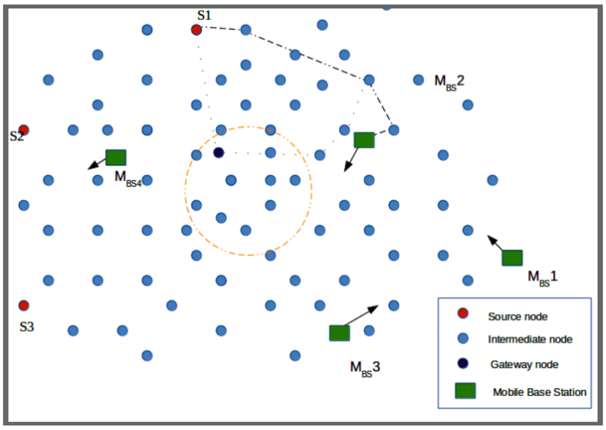

Fig 2. Scenario where the source finally sends the data to the mobile sink

The second scenario is depicted in figure 2. It explains how the routing to the mobile sink converges, as the scenario will be converted similar to elastic routing approach, where the source node finally overhears the transmission from gateway node to the sink.

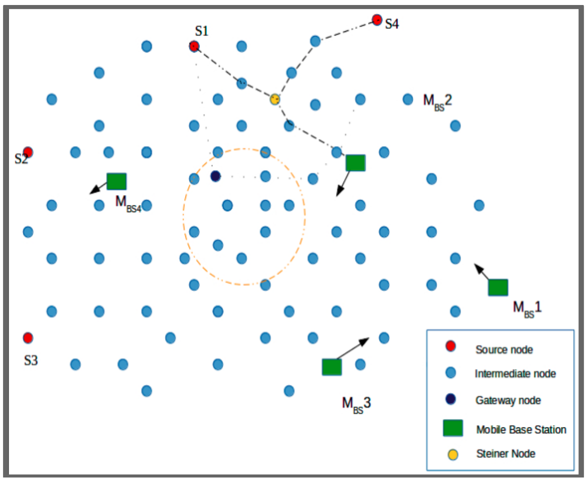

Fig 3 Scenario of multiple sources communicating to the base station

The source S1 will then route the data directly to the mobile sink $M_{BS}2$.When multiple static sources have data to send simultaneously, a Steiner tree concept in geometry is used. A set of Steiner nodes are introduced as shown in the figure 3. The Steiner point in a graph is an extra vertex, which is not a part of the original set of points in the graph, in order to minimise the overall delay in connecting all nodes in the graph. The basic property of Steiner Point is that the sum of distances from all other vertices to it is minimum.

The calculation of Steiner Points proposed in [13], is used in this paper for the calculation of Steiner points for connecting all the sources with the sink. Accordingly, when the Steiner points are determined with respect to other three vertices, it is called as the Fermat's point. We form a triangle with the three coordinates; here one is the source S1, then other source S4 and the mobile base station MBS2, as shown in figure 3. Using that triangle, we construct two equilateral triangles, with one side common with the original triangle. Then, we draw a line from each of the equilateral triangle. The point of intersection of those lines, form the Steiner points of the given set of points.

IV. SIMULATION RESULTS

The proposed approach was simulated using Cooja, a contiki/tinyos simulator. Nodes were programmed using tinyOS. Static nodes were initially deployed in a grid of 7 x 7 pattern. Since the area was uniform, the region in and around node no.25 was taken as a centroid region. Initially a single source node was programmed to send continuous data packets at a rate of 50 pps were deployed. In order to identify the nearby nodes, all nodes will send a single hop broadcast message. All the source nodes were pre-programmed with gateway node address, so that the packets were routed to the centroid region. Mobile nodes were programmed to send continuous beacon packet to the gateway node so that the gateway node always get updated with the location of the mobile node. We used Cooja mobility plugin to simulate the movement of mobile node. The mobility model adopted was random waypoint mobility model with speed of 0.5m/s with a pause time of 3 sec. Since we followed a grid based deployment, the node-id was used to get the location of the node in a coordinate system and hence use this information to route the data. The location of the mobile node is determined using weighted trilateration. We followed the approach proposed in [14] to know the position of mobile node in the field.

Simulation screenshot of a single source and a single sink is shown in the Figure 4. Initially source was programmed to send data to the centroid region with a rate of 50pps (128byte packet at an interval of every 20 millisec). For simulation, we fixed node 25 as our gateway node. Gateway node will calculate an appropriate sink with

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minimum Euclidean distance from the source node to the entire mobile node in the field. As shown in Figure 4, gateway node will redirect the traffic to the mobile nodes near to the sink. Due to overhearing, the routing path will be directed towards the mobile sink with minimum number of hops as shown in Figure 5. The number of hops towards mobile sink initially (via gateway) and direct routing (after elastic routing) is shown in Figure 6. It is clear that the number of hops get reduced from the initial value after a period of time.

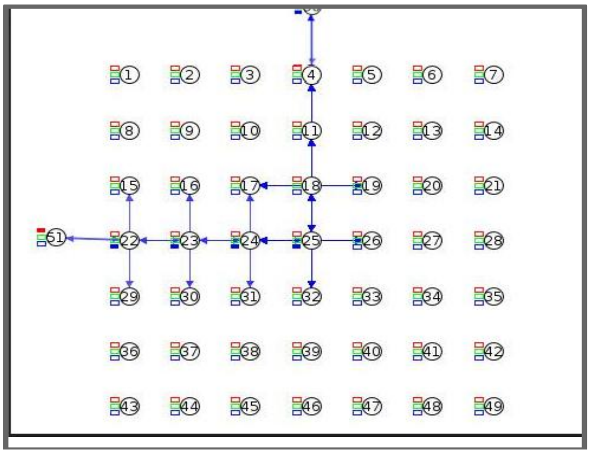

Fig 4: Cooja Screenshot: Single Source Single Sink Via Gateway node

Simulations were also done to test the scenario of multiple sources communicating with a single mobile node. In the case of n sources with m mobile node, where n >> m, gateway node will assign more than one source node to a single mobile node. This scenario can also occur if multiple sources are near to a mobile node which is having less Euclidean distance away from them.

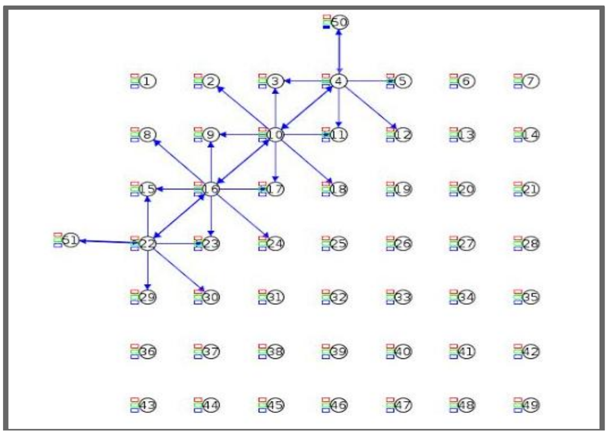

Fig 5: Cooja Screenshot: Single Source Single Sink (direct)

Scenario file was created in Cooja with three sources, communicating to a single mobile node as shown in the Figure 6. The mobile node will calculate the appropriate Steiner points and pass this information to the sources. This is done via elastic routing.

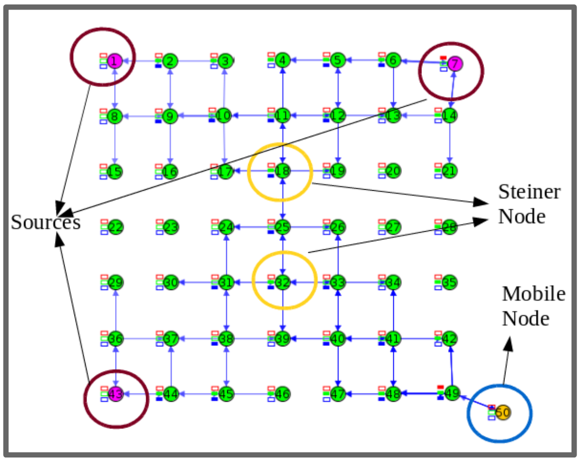

Fig 6 Cooja Screenshot: Multiple Source and Sink routing Via Steiner points

The data path from the sources will be routed to the mobile sink via Steiner nodes as shown in Figure 6. To appreciate the advantage of Steiner tree, separate simulations were done to calculate the cost metrics of SMT, MST and direct routing. Figure 7 and 8 shows the result with respect to the number of nodes in the field as well.

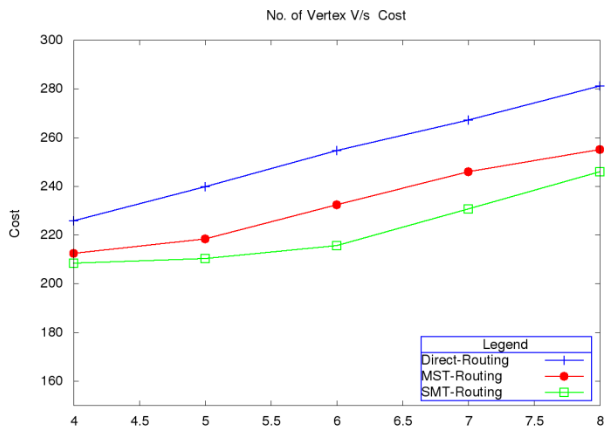

Fig 7 No of Vertex Vs. Cost

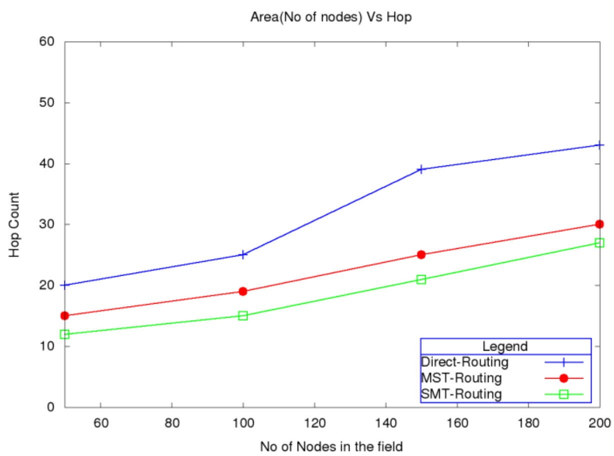

Fig 8: No of Nodes in Field Vs. Hop Count

Figure 7 shows the comparison between no of sources and the cost of the route formed after connecting sources and base station. Figure 8 shows the comparison between direct routing, MST and SMT from three sources and a mobile sink for different area.

Since the size of area is proportional to the number of nodes deployed, comparison was done w.r.t the hop count and no of nodes. From the Figure 7 and 8, it is clear that SMT take minimum number of hops/cost to connect all the sources with the sink.

V. CONCLUSION

The paper aims to provide an efficient routing method for routing the data from multiple static sources to multiple mobile sinks. We propose to use a gateway node in the network for dynamically routing the data to the mobile sink using greedy forwarding. The gateway node is one among the nodes in the centroid region of the network, which has been elected based on an election algorithm. It is then used for selecting the nearest mobile sink closer to the source, which will then forward the data to it using greedy forwarding and in turn route the data directly via elastic routing. The data from multiple static sources are forwarded by introducing Steiner nodes in the network. Steiner Minimum Tree approach is used which provides reduction in many metrics when compared with other protocols including MST and direct routing.

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