Multipath Load Balancing: An Entropy based Clustering Solution for Mobile Ad hoc Networks

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Abstract—Mobile Ad-hoc networks are constrained by constantly changing topology, uncertain channel conditions and limited resources. Routing overhead increases with increased number of nodes and increased traffic. Multipath routing is popular technique used to improve the throughput and provide load balancing. To further enhance scalability and to achieve better quality of service, mobile nodes can be grouped forming clusters to take advantage of the hierarchy in the network. We propose a load balancing solution that distributes traffic across multiple paths for a cluster based routing protocol. Entropy based metric is applied to select cluster heads. Further entropy values of the cluster heads are extended to evaluate the stability of the link formed by the cluster heads. Simulation study show improved performance in terms of better cluster head lifetime and enhanced network performance.

Index Terms—cluster based routing, multipath routing, load balancing, entropy.

I. INTRODUCTION

Mobile ad hoc networks are networks which can be set up instantly without any infrastructure. With the proliferation of different types of wireless devices, MANETs are gaining popularity. These networks are already found to be widely used in military and disaster rescue operations. Of late, use of multimedia based applications are picking up.

Design of efficient routing protocols, is of utmost importance as these networks have to perform under several limitations like error prone channel conditions, mobility of nodes and limited resources like battery power, bandwidth. Another feature of these networks, lie in the disparity among the computing capabilities and energy capacities of the mobile nodes. On-demand routing techniques are preferred as they minimize the overhead due to storing of routing table and exchange of routing messages. But with increased number of nodes, performance of on-demand routing protocols sharply degrades. In addition to this, most of the routing protocols use shortest hop metric, which overburdens nodes part of the shortest path that very often lie in the center of the network. Such overloaded nodes get congested and start dropping packets sometimes leading to network partitions. Applying load balancing schemes to routing protocols, become necessary to push network traffic from the center of the network to less congested links for maximizing network utilization.

Another approach in implementing load balancing solution is by exploiting the hierarchy inside the network. Mobile nodes called cluster heads with high processing and energy power can be entrusted with the responsibility of coordinating transmission events inside the network. This can improve the scalability and network utilization. Further considering the unreliability of the wireless channel and unpredictability of network topology, multiple routes for a source destination pair along the cluster heads can be computed. Flat structural organization of mobile nodes limits the scalability of MANETs. To achieve scalability and to balance the load, hierarchical organization of mobile nodes into clusters is preferred. Special mobile nodes called cluster heads undertake the responsibility of forwarding data on behalf of its members. Clustering has several advantages, in that it facilitates spatial reuse of resources thereby increasing system capacity and also restricts the spreading of routing information to cluster heads[1]. Any change in the topology, can be handled locally without any effecting the other parts of the network thus minimizing the information processed by each mobile node.

We propose a cluster based routing protocol (EBM-CBRP) that discovers link disjoint multiple paths along the cluster heads while route discovery is done. Our protocol evaluates the quality of those multiple paths and accordingly distribute the data traffic along them to attain load balancing. In our work we have restricted multiple paths to two as more number of multiple paths does not achieve additional benefits. One important element of cluster based routing protocols is that of mechanisms for cluster head selection. Selection of stable cluster heads is vital as cluster head instability introduces major overheads. But at the same time, selecting a stable cluster head is equally challenging. Entropy guided approach for cluster head selection is a reasonable approach considering the randomness in MANETs. Therefore we adopt entropy based mechanism to capture the uncertainty involved while selecting cluster heads. In our protocol we combine
mobility and energy entropy to assess the suitability of a node being a cluster head.

The rest of the paper is organized as follows. Section II review status of work and section III deals about the use of joint entropy and section IV about working of the proposed protocol. Simulation study of the proposed protocol is taken up in section V and section VI gives concluding remarks.

II. REVIEW OF LITERATURE

Implementing load balancing solutions for MANETs has been discussed in [2][3][4][5]. All these studies concentrate on mechanisms to detect overloaded nodes and then diverting traffic across less congested paths. Another way of load balancing is implemented by using alternate paths which are less congested and then distributing load across these paths using different traffic distribution policies[6][7][8]. Due to the absence of any centralized infrastructure, routing protocol incurs overhead when number of nodes increase. Balancing the load among the nodes for extending network lifetime gets unwieldy. So grouping a set of nodes into clusters with a centralized cluster head can simplify the problem of load balancing. When clustering is adopted, selection of cluster heads is vital. Several algorithms have been proposed for the selection of cluster heads.

When clustering approach is used cluster heads shoulder greater responsibility of data transmission resulting in the depletion of energy at a faster rate and network partitions. So distributing load among cluster heads is a critical issue. One solution discussed in [9] is by allocating some amount of maximum specified amount of time or budget for every cluster head. Once the specified budget is crossed, then that node ceases to be the cluster head. Initially mobile nodes with the lowest ID in their neighborhoods are chosen as cluster heads in LIC[10]. In HCC[11], the clustering scheme is performed periodically to check the “local highest node degree” attribute of a cluster head. When a cluster head finds a member node with a higher degree, it is forced to relinquish its cluster head role. This mechanism, of course, involves frequent re-clustering. LCC[12] is considered to be a significant enhancement of Lowest ID Clustering (LIC) or Highest Connectivity Clustering (HCC). Distributed Clustering Algorithm (DCA)[13], assigns node-weights based on the suitability of a node as a cluster head. A node is chosen to be a cluster head if its node-weight is higher than any of its neighbor’s node-weight. The nodes are assigned weights which vary linearly with their speeds but with negative slope. Since node-weights are varied in each simulation cycle, computing the cluster heads becomes very expensive. [14][15] discusses use of entropy metric in MANET.

III. JOINT ENTROPY BASED CLUSTER HEAD SELECTION

Entropy is a widely used technique to capture information content within a system. MANETs are characterized by frequent changes in topology introduced by node motion and time varying channel conditions. Hence arriving at a set of suitable metrics to ensure quality of service is quite challenging. Due to the uncertainty and probabilistic nature of wireless networks predicting the network conditions become difficult. Some studies have suggested the suitability of Schanons entropy analogue[16][17]. He devised an equation that would determine the entropy of a system knowing the probability of events occurring. We propose to take advantage of the usefulness of entropy based metric for cluster head selection as choosing a suitable cluster head is a NP-hard problem.

The entropy $H$ of a discrete random variable $X$ is a measure of the amount of uncertainty associated with values of $X$. It is given by

$$H(X) = - \sum_{x \in X} p(x) \log p(x)$$

Joint entropy is used when there are two random variables. It is given by

$$H(X, Y) = - \sum_{x, y} p(x, y) \log p(x, y)$$

where $x$ and $y$ are two random variables.

In this work we have generalized information entropy to relative node motion and node energy. Joint entropy is computed by summing up individual entropies of energy and mobility.

IV. ENTROPY BASED MULTIPATH CLUSTERED ROUTING PROTOCOL (EBM-CBPR)

The main aim of this work is to design a load balancing routing protocol that distributes load across multiple paths formed by the cluster heads as the constituent nodes. Electing stable cluster heads is vital as frequent cluster head changes deteriorate network performance. Nodes in the network are classified into cluster heads and cluster members and cluster gateways. Each cluster head is one hop away from its cluster members. Every cluster member is attached to one cluster head. Id of its cluster head and adjacent cluster heads are stored by each member of a cluster. At the same time, every cluster head maintains a table of its members and neighboring cluster heads. HELLO packets are exchanged between cluster heads and cluster members.

A. Initialization phase.

In this phase every node monitors the number of neighbors it has using HELLO packets. Mobility level of each node is another parameter measured to derive its mobility entropy. Similarly remaining energy values associated with a node are also observed for an interval of time to compute energy entropy.

B. Mobility Entropy

Mobility is often a relative metric. Received signal strength of the HELLO packets is monitored for a time interval to evaluate the relative mobility of a node. Every node maintains a list of neighbors based on the HELLO packets received. If there is a rapid change in the neighbor list, it can be concluded that node in question is fast moving. So it is clear that the receiving power varies as the distance between...
the nodes changes. If the nodes approach towards each other distance becomes minimized which invariably increases the reception power.

Then mobility entropy is given by

\[ H_{mob} = \sum_{i \in X} p(t) \log p(t) \]  \hspace{1cm} (3)

C. Energy Entropy

Decision regarding selecting a cluster head with enough residual power for sustained data transmission is often difficult due to the uncertainty and randomness involved in the network conditions. Entropy metric is again a suitable one to measure the uncertainty. Let \( f(y) \) the probability density function of the observed remaining energy values for a period of interval at a node.

Energy entropy is given by

\[ H_{energy} = \int f(y) \log f(y) dy \]  \hspace{1cm} (4)

After this Joint entropy is derived that gives a collective measure of the suitability of a node being a cluster head. As mobility and energy associated are statistically independent variables, joint entropy of a node is calculated using sum of their independent entropy values.

\[ H(mob,energy) = H_{mob} + H_{energy} \]  \hspace{1cm} (5)

Every node exchanges its instantaneous joint entropy using (5) and its degree with neighboring nodes. A node with highest degree and lowest joint entropy value will be elected as the cluster head.

B. Multiple Route selection.

Once cluster heads are formed, Route Discovery is initiated to discover multiple paths via cluster heads. To facilitate the computation of multiple paths, AOMDV[18] is chosen to be the routing protocol. Route Request packet generated by a node is unicast to its cluster head. Cluster head takes the responsibility of finding the route by broadcasting it to adjacent cluster heads. Every intermediate node, if it is a cluster head and if it has not seen this RREQ packet earlier forwards it. Currently observed joint Entropy values of energy and mobility is inserted in to RREQ packet by each node which forwards it. Destination on receiving the RREQ will calculate the quality of the link by observing the joint entropy value of the link. Destination will select 2 paths with lowest joint entropy value and sends RREP for these paths.

IV. PERFORMANCE EVALUATION

To study the performance of our proposed algorithm simulation was conducted using Omnet ++[20] which supports complete physical, data link and MAC layer models for simulating wireless ad hoc networks. We simulated a network of mobile nodes placed randomly in an area of 500 x 500 square meters, with mobile nodes ranging from 10 to 50. A source and a destination is selected randomly. Free space propagation model is assumed as the channel model.

Each node is assumed to have a constant transmission range of 250 meters and a channel capacity of 2 Mbps. Medium access control protocol used is 802.11 DCF. Mobility pattern of the mobile nodes is generated using Random waypoint model. A mobile selects another node in the network and constantly moves towards it at a given velocity. Once it reaches there, it waits for some pause time and selects another node and again starts moving. By observing the performance of the network under mobility we can test the stability of the design in real time scenario. Speed of a mobile node is assigned a value between 0 to 20 meters/sec. The performance parameters studied for our simulation study was life time of the cluster and packet delivery fraction by varying the node density and pause time. Performance evaluation of our protocol is compared with CBRP[19].

A. Results.

Figure 1. shows packet delivery ratio achieved by our proposed protocol EBM-CBRP. Improved packet delivery ratio is achieved due to the fact that our protocol is able to choose stable paths guided by entropy metric. Increasing number of nodes does not affect the packet delivery ratio as is normally the case with other routing protocols.

![packet delivery ratio vs nodes](image)

Figure 1: Achieved packet delivery ratio by varying number of nodes

The amount of pause time determines the level of mobility of the nodes. More pause time for a node would mean lesser level of mobility of a node. We have studied the effect of mobility on the performance of the proposed protocol. Compared to CBRP our protocol performs well under high level of mobility. Figure 2 shows this.
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The advantage of cluster based routing can be inferred from figure 3 which shows improvement in the cluster lifetime. Lifetime of a cluster head is a clear indication of stability of our protocol. Lesser lifetime of a cluster-head leads to increase in control overhead due to reorganization of clusters. As seen increase in node density does not effect the lifetime of the cluster head.

Cluster head stability is an important parameter of interest. It is very important for the cluster head to be stable. Figure 4 shows effect of pause time cluster lifetime.

V. CONCLUSION

Multipath routing is used to achieve load balancing by distributing traffic across multiple paths. We have enhanced upon multipath routing by organizing group of nodes into clusters and designating high capability nodes as cluster heads. These cluster heads are later explored to generate multiple paths. This measure reduces interference among multiple paths. Joint entropy based selection of cluster heads is done to attain stable multiple paths using mobility and energy values. Performance evaluation of our method shows improvement in terms of minimum cluster head changes and increased packet delivery ratio.

REFERENCES


