Topology and Routing in Computational Capacity Evaluation of Ad hoc Networks

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Summary
The Ad hoc networks are the wireless networks where the communication takes place through the different nodes. For example, in mobile Ad hoc network, the data is transmitted and received through the different mobile nodes. Other example may include the laptops, smart homes etc. Main issue in the Ad hoc network is the life time of batteries which are used by the different nodes. Battery life depends on the amount of information transmission and number of hops. For optimal use of battery life, different data routing algorithms are reported in literature. This paper basically presents the brief overview of the computational capacity maximization approaches and also summarizes the critical analysis of the existing routing protocols. In addition, this paper discusses the topology related issues. In general, the nodes are deployed randomly and most of the routing protocols refer this topology. The geometrical topology is also discussed in this paper to design the routing algorithm. With the consideration of mobility of nodes, one can design the routing algorithm where once the nodes location geometry shape is identified, the same shape can be used for the changed position of the nodes with deletion or insertion of nodes.

Key words:
Ad hoc network, Computational capacity, Routing protocols, Static and dynamic routing, Network topology

1. Introduction

Wireless networks consist of a number of nodes which communicate with each other over a wireless channel. Some wireless networks have a wired backbone with only the last hop being wireless. Examples are cellular voice and data networks and mobile IP. In others, all links are wireless. One example of such networks is multi-hop radio networks or Ad hoc networks. Another possibly futuristic example, see [1], may be collections of *smart homes* where computers, microwave ovens, door locks, water sprinklers, and other *information appliances* are interconnected by a wireless network.

Wireless Ad hoc networks [2] have known considerable interest recently due to their decentralized feature. A wireless Ad hoc network is a network where a packet of data information from the transmitting handset (known as a node) is sent through different nodes (by multiple hops) to the final destination (path (2) in Figure 1). This transmission scheme is supposed to increase the flexibility of deploying information infrastructures to cover a given number of users (compared with the case where the information is centralized by a base station, path (1) in Figure 1).

However, a key issue in data communications with small portable handsets concerns the maximization of battery life (due to energy dissipation in Joules) as well as the efficiency of the network (or data rate in bits/s/Hz). More precisely, considering a given energy at hand for the whole network (total energy of all the handsets), we would like to maximize the number of reliably transmitted bits per joule, rather than the number of bits per second per hertz (spectral efficiency).

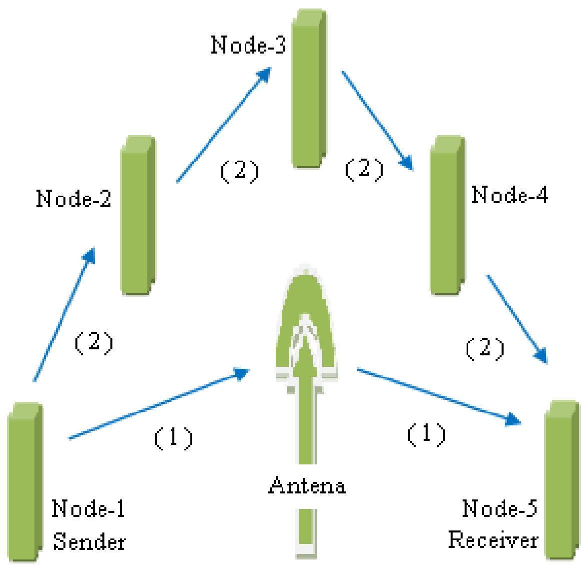

Fig. 1: Wireless Ad hoc Network

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This paper basically deals with the overview of different approaches available for the evaluation of computational capacity of the Ad hoc network. It mainly focuses on the key issues and information routing algorithms in Ad hoc network. It is organized as follows: Section 2 summarizes the key issues in Ad hoc network and computational capacity related work is discussed in the section 3. Section 4 and section 5 discusses the node topologies and the routing protocols respectively. The paper ends with the discussion and conclusion which is given in section 6.

2. Key Issues in Ad Hoc Network

2.1 Asymmetric links

Most of the wired networks rely on the symmetric links which are always fixed. But this is not a case with Ad hoc networks as the nodes are mobile and constantly changing their position within network. For example consider a MANET (Mobile Ad hoc Network) where node B sends a signal to node A but this does not tell anything about the quality of the connection in the reverse.

2.2 Routing Overhead

In wireless Ad hoc networks, nodes often change their location within network. So, some stale routes are generated in the routing table which leads to unnecessary routing overhead.

2.3 Interference

This is the major problem with mobile Ad hoc networks as links come and go depending on the transmission characteristics, one transmission might interfere with another one and node might overhear transmissions of other nodes and can corrupt the total transmission.

2.4 Dynamic Topology

This is also the major problem with Ad hoc routing since the topology is not constant. The mobile node might move or medium characteristics might change. In Ad hoc networks, routing tables must somehow reflect these changes in topology and routing algorithms have to be adapted. For example, in a fixed network routing table updating takes place for every 30sec. This updating frequency might be very low for Ad hoc networks.

2.5 Computational Capacity

The network capacity is a very important parameter to evaluate the performance of Ad hoc network. In fact, the achievable capacity of Ad hoc networks with battery consumption has not yet been determined and can put at stake the Ad hoc network hype. Usual studies of Ad hoc network based on diversity considerations [3] assume that the information going through a node uses only the transmitted power of that specific node (and not the energy related to the process of information). A recent article of Goldsmith et al. [4] based on energy consumption simulations show that this energy can not be neglected. Mathematically, we can formulate the problem as the multi objective and/or single objective optimization problem. The problem formulation is the maximization of bits (reliably transmitted) per joule and/or maximization of battery life of node and/or maximization of the efficiency of the network subject to the constraints of limited battery life of nodes, transmission power of nodes, and energy related to the process of information (transmitted through nodes). So, this problem can be formulated as the single objective or multi objective optimization problem.

3. Computational Capacity Related Work

In fact, all physical systems register and process information [5, 6]. The laws of physics determine the amount of information that a physical system can register (number of bits) as well as the number of elementary logic operations that a system can perform (number of operations). Recent results in physics have shown that the number of elementary logical operations per second that a physical system can perform is limited by the system's energy and that the amount of information that the system can register is limited by its maximum entropy. Based on these results, Lloyd [7] derived the physical limits of computation of a node.

There has been much research on determining the optimal rates to maximize throughput via Linear Programming (LP) formulations. The first attempts can be traced back to Hajek and Sasaki [8], and to Baker et al. [9]. Jain et al. [10] propose LP-formulations for max-flow and related problems in a wireless network; in fact, they formulate their constraints in terms of arbitrary conflict graphs which can incorporate any interference model. Their formulations do not fully exploit the properties of wireless interference constraints; further, they do not discuss how close their LP-formulations are with respect to the optimal solution, or how actual scheduling protocols can be derived from the LP solution.

Over the last few years, the capacity of random wireless Ad hoc networks has been a subject of active research; see [11, 12, 13, 14, 15, 16, 17, 18, 19] and the references therein. Researchers have considered random Ad hoc networks, hybrid networks wherein one has infrastructure support, energy constraints, maximum power range constraints and mobility effects.

Piyush Gupta and et al. [14] shown that under a protocol model of noninterference, the capacity of wireless networks with randomly located nodes each capable of transmitting at W bits per second and employing a common range, and each with randomly chosen and therefore likely far away destination, is $\theta\left(W/\sqrt{n\log n}\right)$. This is true whether the nodes are located on the surface of a three-dimensional sphere or on a planar disk. Even when the nodes are optimally placed in a disk of unit area, and the range of each transmission is optimally selected, a wireless network cannot provide a throughput of more than $\theta\left(W/\sqrt{n}\right)$ bits per second to each node for a distance of the order of 1 meter away. In fact, summing over all the bits transported, a wireless network on a disk of unit area in the plane cannot transport a total of more than $\theta\left(W\sqrt{n}\right)$ bit-meters per second, irrespective of how the load is distributed. Under a physical model of noninterference, the lower bounds are the same as those above for the protocol model, while the upper bounds on throughput are $\theta\left(W/\sqrt{n}\right)$ for random networks.

In [20], the effects of multi-packet reception (MPR) capability on the capacity of wireless networks with regular structures are analyzed. Under uniform traffic and minimum connectivity, the maximum stable packet generation rate for the MPR Manhattan networks is obtained. For a network of size *N*, it is shown that the capacity is $K_1/\sqrt{n}$ and adding MPR affects the coefficient K_1 of a non-MPR network by no more than 1.6 times. For the same network the stability region of the slotted ALOHA random access protocol with MPR is shown to be $K_2/\sqrt{n}$, for some constant $K_2 < K_1$.

For increased connectivity, it is shown that the capacity can be increased further by adding MPR. In the limiting case, in a fully connected network, MPR increases the capacity linearly. These results indicate that minimum connectivity for MPR networks is not necessarily optimal. For non-uniform traffic, MPR can contribute much more to particular nodes which have *sink* type of traffic, and the dual concept of multi-packet transmission (MPT) is very useful for *source* type of nodes. In other words, MPR and MPT can boost the throughput of the network also by being selectively added to the nodes that bottleneck the performance.

In [20], the capacity of regular networks with MPR capability related results are presented where MPR alone increases capacity of minimal connected Manhattan Network at most 1.6 times, and random access MAC only affects the coefficient of the capacity. The minimal connectivity is not necessarily optimal for MPR networks. MPR is a subject that requires further investigation in arbitrary topologies and arbitrary traffic patterns. MPR and MPT can boost the performance of the networks also by being selectively added to the nodes in the congested regions of the network.

In [3], the asymptotic throughput capacity of large mobile wireless Ad hoc networks is examined where it is shown that direct communication between sources and destinations alone cannot achieve high throughput, because they are too far apart most of the time. M. Grossglauser and et al. [3] proposed to spread the traffic to intermediate relay nodes to exploit the multiuser diversity benefits of having additional routes between a source and a destination where $\theta\left(\sqrt{n}\right)$ intermediate relay nodes are necessary. M. Grossglauser and et al. [3] assumes the complete mixing of the trajectories of the nodes in the network. It would be interesting to study how much throughput can be achieved when nodes have less random mobility patterns. Recent results suggest that high throughput per SD (Source-Destination) pair is still achievable even when the nodes' mobility is much more constrained [21].

With the rapid increase in low cost sensor devices, there is an increased interest in the deployment of Ad hoc wireless sensor networks. This is reflected in the recent spurt of research interest in this area [22, 23]. Low cost sensors typically have low battery life and therefore conserving battery energy is a prime consideration in these networks. Since some battery energy is depleted for each message transmission, it is necessary to use energy aware and energy conserving routing algorithms.

In [24], the distributed algorithm for on-line message routing in energy-constrained wireless Ad hoc networks is proposed. In this algorithm for routing of messages in Ad hoc networks, the nodes are energy-constrained. Here the routing objective is to maximize the total number of messages that can be successfully sent over the network without knowing any information regarding future message arrivals or message generation rates. From a theoretical perspective, if admission control of messages is permitted, then the worst-case performance of algorithm is within a factor of *O*(log(network size)) of the best achievable solution. In other words, this algorithm achieves a logarithmic competitive ratio. This approach provides sound theoretical backing for several observations that have been made by previous researchers. From a practical perspective, the algorithm is good even in the absence of admission control, and that it also performs better than previously proposed algorithms for other suggested metrics such as network lifetime maximization. This algorithm uses a single shortest path computation. The performance impact of inexact knowledge of residual battery energy and the impact of energy drain due to dissemination of residual energy information is also evaluated by simulations.

The stability and the capacity problems in packetized wireless networks are studied in [25]. Communication medium is modeled using probability density functions that determine the packet reception probabilities. The model includes several previous models as special cases, and it is suitable for networks with time-varying topology and channels. Main result is a characterization of the stability and the capacity regions using network flows. A class of control policies sufficient to achieve every rate inside these regions is introduced. Latter, the proposed policies and the flow analysis is applied to regular networks. Closed-form expressions for the capacity of Manhattan networks (two-dimensional grid) and ring networks (circular array of nodes) are obtained. Analysis of the performance loss due to suboptimal medium access and routing is worked out. In [25], the impact of link fading, link state information, and variable connectivity on achievable rates in Manhattan networks are investigated.

In [16], the capacity of a power constrained Ad hoc network with an arbitrarily large bandwidth is studied. Examples of such a network include UWB (Ultra Wide Bandwidth) [26] and sensor networks. It is shown that for such a network, consisting of *n* randomly distributed identical nodes over a unit area, with probability approaching one (as $n \rightarrow \infty$), the uniform throughput capacity $r(n)$ is $O\left((n \log n)^{\frac{\alpha-1}{2}}\right)$ (upper bound) and $\Omega\left(\frac{n^{(\alpha-1/2)}}{(\log n)^{(\alpha-1/2)}}\right)$ (lower bound). Thus, the throughput capacity $r(n)$ for such a random Ad hoc network is $\theta\left(n^{(\alpha-1/2)}\right)$ interestingly, this bound demonstrates an increasing per-node throughput, in comparison to the decreasing per-node throughput shown in [14]. The key reason for this contrasting result is that Negi and Rajeswaran [16] assumes finite power, large bandwidth, and the explicit use of link adaptation. Thus, the properties of the physical layer dramatically alter the Ad hoc network capacity.

Research work in [27] considers two inter-related questions: (i) Given a wireless Ad hoc network and a collection of source-destination pairs, what is the maximum throughput capacity of the network, i.e. the rate at which data from the sources can be transferred to their corresponding destinations in the network? (ii) Can network protocols be designed that jointly route the packets and schedule transmissions at rates close to the maximum throughput capacity? Much of the earlier work focused on random instances and proved analytical lower and upper bounds on the maximum throughput capacity. Here, arbitrary wireless networks are considered. The algorithmic aspects of the above questions: the goal is to design provably good algorithms for arbitrary instances are studied. Analytical performance evaluation models and distributed algorithms are developed for routing and scheduling which incorporate fairness, energy and dilation (path-length) requirements and provide a framework for utilizing the network close to its maximum throughput capacity.

Wireless mesh networks (WMNs) have emerged as a key technology for next-generation wireless networking, the relevant survey is presented in [28]. Because of their advantages over other wireless networks, WMNs are undergoing rapid progress and inspiring numerous applications. However, many technical issues still exist in this field. In order to provide a better understanding of the research challenges of WMNs, this article presents a detailed investigation of current state-of-the-art protocols and algorithms for WMNs. Open research issues in all protocol layers are also discussed, with an objective to spark new research interests in this field.

4. Topology

4.1 Random Nodes

In general, the node positions are not fixed in wireless Ad hoc network. Location of the nodes follows the Poisson distribution i.e. random distribution. Therefore, this type of deployment of the nodes falls in the random topology category as shown in Figure 2. In random deployment the distribution of the nodes is represented by the equation 1.

Node Location = Position (*Ran(x), Ran(y)*) (1)

Where Ran represents the random number function, x represents the first coordinate in two dimensional grid and y represents the second coordinate in two dimensional grid for the particular node.

In Figure 2, maximum 20 nodes are considered which are deployed randomly. For the simulation purpose, the following Pseudo code can be used for the node deployment.

```
Define 2-D Grid of M x N size;
Define Maximum number of nodes as NN;
For 1 to NN
{ Find x and y coordinates ( )
    {   Ran(x);   //x should be from 1 to M//
        Ran(y);   //y should be from 1 to N//    }
 Deploy Node;
}
```

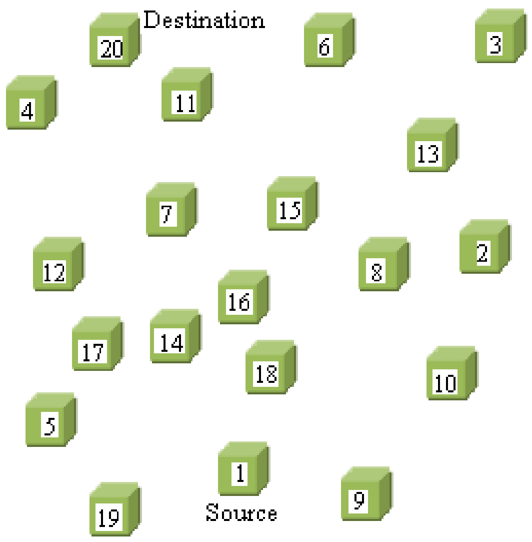

Fig. 2: Random Topology

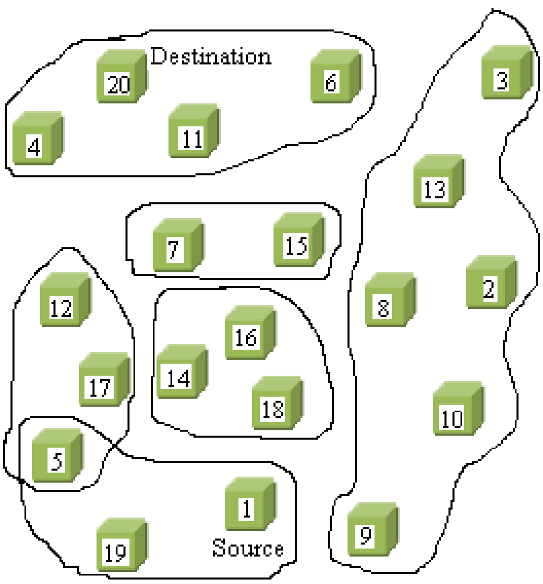

Fig. 3: Groups of Nodes Formed Through Strategic Topology

4.2 Strategic Nodes

We can solve the problem of mobility of nodes which affects the initial topology of the node deployment. If we try to fit the initial random deployment to the typical geometrical shapes e.g. triangles, squares, circles etc. Later we can keep the track of the node positions and try to fit to the typical geometric shape which previously identified and recorded. In place of considering the deployment as random, we can consider it as the strategic deployment and accordingly, we can evolve the available/applied routing algorithm based on the positions and shape data of the nodes. For example, in Figure 2, random deployment of the nodes is shown. Figure 3 shows the groups of nodes formed through the strategic deployment. If we apply the strategic deployment strategy to these randomly deployed nodes, then we can have the results with the possible shapes as shown in Figure 4.

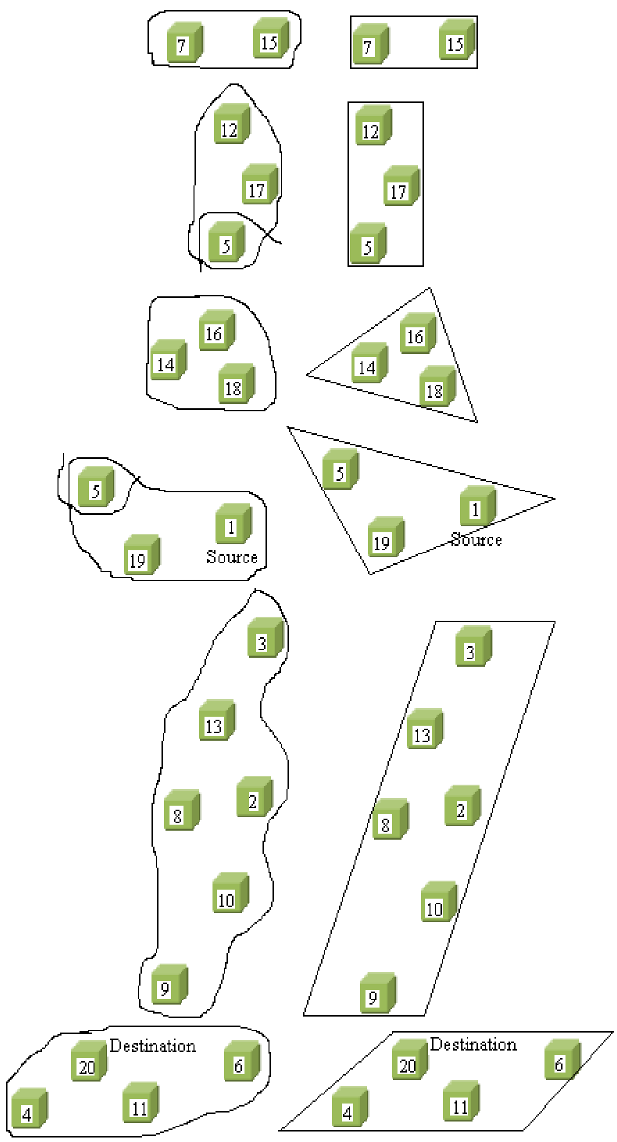

Fig. 4: Possible Shapes with Strategic Topology

Firstly one can record these shapes and same can be used for the changed positions of the node. These changed positions may occur due to the mobility of the nodes. In changed position, there may be the insertion of new nodes or deletion of old nodes for the typical shape. By taking care of this, one can design the data routing procedure.

5. Routing Protocols

5.1 Routing

Routing basically involves two activities: Firstly, determining optimal routing paths which could be very complex. Secondly, transferring the information groups (called packets) through an internetwork, it is called as packet switching which is straight forward. Routing is mainly classified into two categories i.e. static routing and dynamic routing.

Static routing: It refers to the routing strategy being stated manually or statically, in the router. Static routing maintains a routing table usually written by a networks administrator. Routing table doesn't depend on the state of the network status, i.e., whether the destination is active or not. The main disadvantage of static routing is if a new router is added or removed in the network then it is the responsibility of the administrator to make the necessary changes in the routing tables.

Dynamic routing: It is mainly depends on the state of the network i.e., the routing table is affected by the activeness of the destination. The main advantage of dynamic routing is, as each router announces its presence by flooding the information packet in the network so that every router within the network learns about the newly added or removed router and its entries.

5.2 Designing of Routing Protocols

Generally following parameters are considered in designing of routing protocols.

(i) Bandwidth optimization
(ii) Power control
(iii) Transmission-quality enhancement
(iv) Network configuration
(v) Topology maintenance
(vi) Efficient / Reliable routing
(vii) TCP issues

5.3 Basic Categories

In general the basic categories of routing protocols are based on the routing style. These probable categories are as follows.

(i) Proactive routing protocols
(ii) Reactive routing protocols
(iii) Region based hierarchical routing protocols
(iv) Cluster based routing protocols
(v) Central node based routing protocols
(vi) Position based routing protocols
(vii) Link based routing protocols
(viii) Multicast routing protocols

In literature numerous protocols are reported which can be classified on the basis of above categories. Few of the protocols which are critically analyzed and the results are summarized in the Table 1 and Table 2.

Table 1 summarizes the protocol categories and relevant approaches. Table 2 gives the details of the basic evaluation parameters related to the relevant protocols.

6. Discussion and Conclusion

Computational capacity is the key issue in the Ad hoc network. Numerous contributions exist related to the computational capacity maximization. In this paper, we have identified that mathematically this problem is the optimization problem with single or multi objectives with some constraints. This problem can be formulated as the non linear constrained optimization problem. Information traversing is the main thing which affects the computational capacity of Ad hoc network. Therefore it becomes necessary that we should have some criteria for the traversal of the information. This criterion is the routing protocols which are used for the data transmission amongst the nodes. In routing protocol designing, the node topology is very important and in general it is considered as the random means the network follows the random topology.

In the presented work, we have designed the shape based strategic topology which can be used in consideration of mobility of nodes when to design any routing algorithm. From implementation or simulation point of view, one can use the graphs and trees for this. Existing routing algorithms are critically analyzed with respect to the category, fundamental approach, casting, basic evaluation parameter, and number of paths. In future, shape based strategic topology can be used to design the heuristic routing algorithm with the consideration of constraints like transmission range, battery life, energy related to the processing of information etc. As the computational capacity maximization is the optimization problem, it can be solved by using the advanced optimization methods like genetic algorithm, ant colony optimization, and particle swarm optimization. This paper can be helpful to those who are interested in designing the routing algorithm.

Table 1: Protocol Categories and Relevant Approaches

Protocols	Protocol Category	Approach	References
The Wireless Routing	Proactive routing protocols	Uniform routing	[29]
The Destination Sequence Distance Vector Routing		Distance based and uniform routing	[30]
The Fisheye State Routing		Uniform routing	[31]
The Dynamic Source Routing	Reactive routing protocols	Route discovery and maintenance	[32]
The Ad hoc On-demand Distance Vector Routing		Routing table based	[33]
The Temporally Ordered Routing Algorithm		Graph based	[34, 35]
The Zone Routing	Region based hierarchical routing protocols	Zones based on the distances between mobile nodes	[36,37]
The Hybrid Ad hoc Routing		Tree based	[38]
The Zone-based Hierarchical Link State Routing		Geographical information based	[39]
The Cluster-head Gateway Switch Routing	Cluster based routing protocols	Cluster member table based	[40]
The Hierarchical State Routing		Hierarchical addressing based	[41]
Cluster Based Routing		Neighbor table based	[42]
Landmark Ad hoc Routing	Central node based routing protocols	Non uniform routing and scalable	[43]
The Core-Extraction Distributed Ad hoc Routing		Central node based	[44]
The Optimized Link State Routing		Link state information based	[45]
Location Aided Routing	Position based routing protocols	Range estimation of the destination	[46]
The Distance Routing Effect Algorithm for Mobility		Geographical information based	[47]
The Grid Location Service		Geographical information based	[48]
The Link Associativity Based Routing	Link based routing protocols	Degree of link association stability	[49]
The Signal Stability-Based Adaptive Routing		Dynamic and static routing based	[50]
The Ad hoc Multicast Routing	Multicast routing protocols	Tree and core based	[51]
The Ad hoc Multicast Routing utilizing Increasing id-numberS		Tree based	[52]
The On-Demand Multicast Routing		Mesh and group forwarding based	[53, 54]
The Core-Assisted Mesh		Mesh and core based	[55, 56]

Table 2: Basic Evaluation Parameters of Routing Protocols

Protocol	Multicasting (Yes (Y)/No (N))	Evaluation Parameter	Number of Paths (Multiple (M)/ Not Multiple (NM))	References
The Wireless Routing	N	Path (shortest)	NM	[29]
The Destination Sequence Distance Vector Routing	N	Path (shortest)	NM	[30]
The Fisheye State Routing	N	Path (shortest)	M	[31]
The Dynamic Source Routing	N	Path (shortest)	M	[32]
The Ad hoc On-demand Distance Vector Routing	Y	Path (shortest)	M	[33]
The Temporally Ordered Routing Algorithm	N	Path (shortest)	M	[34, 35]
The Zone Routing	N	Path (shortest)	M	[36,37]
The Cluster-head Gateway Switch Routing	N	Path (shortest)	NM	[40]
The Link Associativity Based Routing	N	Link Association	NM	[49]
The Signal Stability-Based Adaptive Routing	N	Signal Stability	NM	[50]

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