A Survey on Routing Protocols in Wireless Sensor Network

Sandeep Sharma

Abstract Now-a-days energy-efficient routing in wireless sensor network is an important research issue. Due to limited battery-power sensor nodes are highly energy constrained. So to enhance the lifetime of sensor network we need energy-efficient routing protocol. According to network topology, routing protocol can be divided into flat and hierarchical routing protocol. This paper surveys different energy-efficient routing protocols and compares their performance. Moreover, the drawbacks of existing routing protocols are also discussed. The paper concludes with open research issues.

Keywords: Wireless sensor network, Routing protocol, Energy-efficiency, network lifetime

— — — — — — — — — ◆ — — — — — — — — —

1   INTRODUCTION

A WSN is a collection of wireless nodes with limited energy capabilities that may be mobile or stationary and are located randomly on a dynamically changing environment. The routing strategies selection is an important issue for the efficient delivery of the packets to their destination. Such sensors can be widely deployed for commercial, civil and military applications such as surveillance, vehicle tracking, climate and habitat monitoring intelligence, medical and acoustic data gathering.

A WSN is composed of large number of sensor nodes which are very small in size, they have limited computational, storage, sensing and power built in capabilities, structure of a typical wireless sensor node is given in Fig 1. It has four main component, one is sensing which is normally used for sensing any physical activity, while the second component is Analog to Digital Converter (ADC) which is used for converting of signal from analog to digital. The third component is processing and computation, which have limited capabilities for computation, while the last component is it power unit, which is responsible for sensor nodes life.

Usually sensor nodes are scattered in the sensing field. They coordinate among themselves to get information about the physical environment. The information is routed to the Base Station either directly or through other sensor nodes. The BS is either a fixed or mobile node which is capable to connect the sensor network to the internet where user can access and process data.
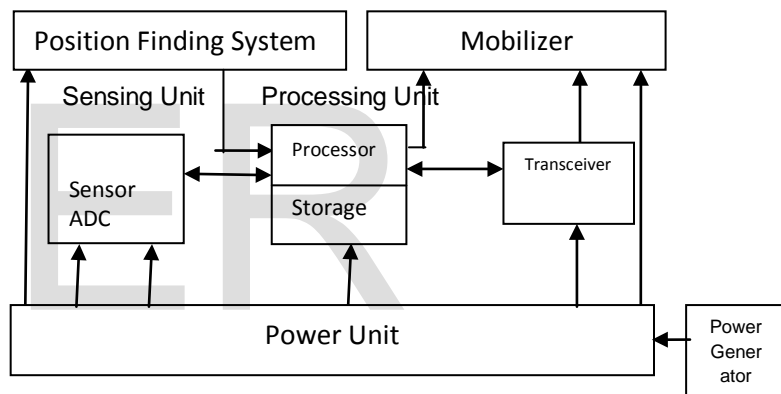

Fig1 The Components of a Sensor Node

Research Issues and Challenges

Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks. First of all, it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, in contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink. Third, generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy

and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management.

The key challenge in sensor networks is to maximize the lifetime of sensor nodes due to the fact that it is not feasible to replace the batteries of thousands of sensor nodes. Therefore, computational operations of nodes and communication protocols must be made as energy efficient as possible.

Considering the challenges of WSN many routing protocols have been already proposed for WSN. They can be classified into flat and hierarchical network routing. In flat routing all nodes are typically assigned equal roles or functionality. SPIN (Sensor Protocols for Information via Negotiation) [1] and DD (Directed Diffusion) [2] fall in this category. In hierarchical routing the network is divided into clusters to achieve energy efficiency. LEACH [5], TEEN [3], APTEEN [4] are well known hierarchical routing protocol.

In addition to the above routing protocols can be classified into three categories namely proactive, reactive and hybrid protocols depending on how the source finds a route to the destination. In proactive, all routes are computed before they are really needed, while in reactive protocols routes are computed on demand. Hybrid protocols use a combination of these two ideas.

The paper is organized as follows. In this section, we have briefly discussed the system architecture design issues and challenges for sensor networks and their implications on data routing. In the section 2, data-centric routing approaches are covered. Section 3 summarizes hierarchical routing protocols. Section 4 describes Location-based routing protocols. Finally, section 5 concludes the paper summary of the surveyed approaches and points out open research problems.

2   Data-centric protocols

In data-centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. SPIN [6] is the first data-centric protocol. Later, Directed Diffusion [2] has been developed and has become a breakthrough in data-centric routing.

Flooding and Gossiping: Flooding [10] and gossiping [9] are two classical mechanisms to relay data in sensor

networks without the need for any routing algorithms and topology maintenance. In flooding, each sensor receiving a data packet broadcasts it to all of its neighbors and this process continues until the packet arrives at the destination or the maximum number of hops for the packet is reached.
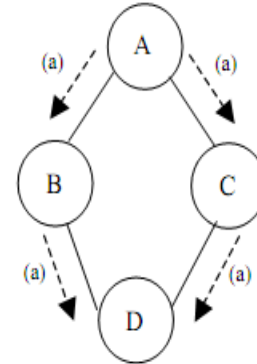

Fig2-The implosion problem

On the other hand, gossiping is a slightly enhanced version of flooding where the receiving node sends the packet to a randomly selected neighbor, which picks another random neighbor to forward the packet to and so on. Although flooding is very easy to implement, it has several drawbacks. Such as implosion caused by duplicated messages sent to same node, overlap when two nodes sensing the same region send similar packets to the same neighbor and resource blindness by consuming large amount of energy without consideration for the energy constraints [10]. Gossiping avoids the problem of implosion by just selecting a random node to send the packet rather than broadcasting. However, this cause delays in propagation of data through the nodes.

Sensor Protocols for Information via Negotiation: (SPIN) [6] Before transmission, meta-data are exchanged among sensors via a data advertisement mechanism, which is the key feature of SPIN. Each node upon receiving new data, advertises it to its neighbors and interested neighbors, SPIN solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness thus, achieving a lot of energy efficiency. There is no standard meta-data format and it is assumed to be application specific, e.g. using an application level framing. There are three messages defined in SPIN to exchange data between nodes. These are: ADV message to allow a sensor to advertise a particular meta-data, REQ message to request the specific data and DATA message that carry the actual data. SPIN gives a factor of 3.5 less than flooding in terms of energy dissipation and meta-data negotiation almost halves the redundant data. However,

SPIN's data advertisement mechanism cannot guarantee the delivery of data. For instance, if the nodes that are interested in the data are far away from the source node
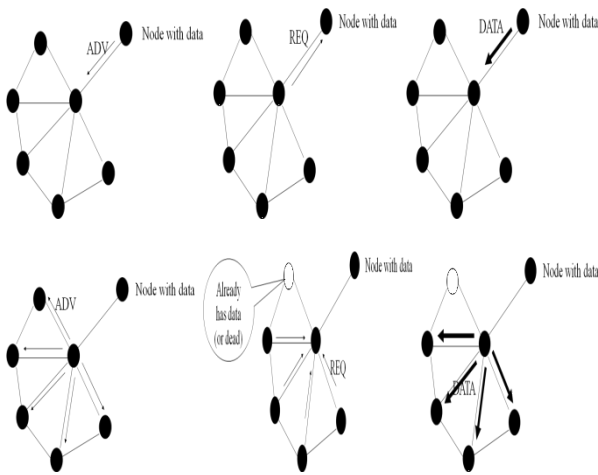

Fig3- SPIN Protocol

and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all. Therefore, SPIN is not a good choice for applications such as intrusion detection, which require reliable delivery of data packets over regular intervals.

Directed Diffusion: [2] It suggests the use of attribute-value pairs for the data and queries the sensors in an on demand basis by using those pairs. In order to create a query, an interest is defined using a list of attribute-value pairs such as name of objects, interval, duration, geographical area, etc. The interest is broadcast by a sink through its neighbors. Each node receiving the interest can do caching for later use. The interests in the caches are then used to compare the received data with the values in the interests.
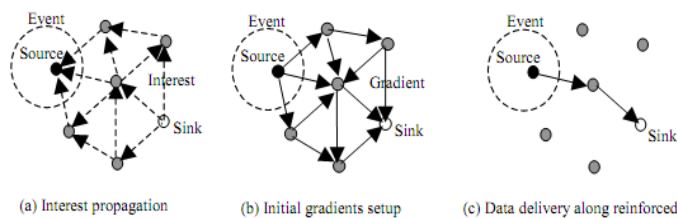

Fig4 – Directed Diffusion Protocol

The interest entry also contains several gradient fields. A gradient is a reply link to a neighbor from which the interest was received. Hence, by utilizing interest and gradients, paths are established between sink and sources.

Several paths can be established so that one of them is selected by reinforcement. The sink resends the original interest message through the selected path with a smaller interval hence reinforces the source node on that path to send data more frequently.

Rumor routing: Rumor routing [12] is a variation of Directed Diffusion. It is an alternative approach used to flood the events if number of events is small and number of queries is large. It is between event flooding and query flooding. The idea is to route the queries to the nodes that have observed a particular event rather than flooding the entire network to retrieve information about the occurring events.

In order to flood events through the network, the rumor routing algorithm employs long lived packets, called agents. When a node detects an event, it adds such event to its local table and generates an agent. Agents travel the network in order to propagate information about local events to distant nodes. When a node generates a query for an event, the nodes that know the route, can respond to the query by referring its event table. Hence, the cost of flooding the whole network is avoided. Rumor routing maintains only one path between source and destination as opposed to Directed Diffusion where data can be sent through multiple paths at low rates.

Simulation results have shown that rumor routing achieves significant energy saving over event flooding and can also handle node's failure. However, rumor routing performs well only when the number of events is small.

3   Hierarchical Routing Protocols

The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink.

Low-Energy Adaptive Clustering Hierarchy: The LEACH protocol is a hierarchical protocol in which most nodes transmit to cluster heads [7], [8]. The operation of the LEACH protocol consists of two phases:

• The Setup Phase. In the Setup Phase, the clusters are organized and the cluster heads are selected. The cluster heads aggregate, compress and forward the data to the base station. Each node determines whether it will become a cluster head, in this round, by using a stochastic algorithm

at each round. If a node becomes a cluster head for one time, it cannot become cluster head again for P rounds, where P is the desired percentage of cluster heads. Thereafter, the probability of a node to become a cluster head in each round is 1/P. This rotation of cluster heads leads to a balanced energy consumption to all the nodes and hence to a longer lifetime of the network.

• The Steady State Phase. In the Steady State Phase, the data is sent to the base station. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead. Moreover, each node that is not a cluster head selects the closest cluster head and joins that cluster. After that the cluster head creates a schedule for each node in its cluster to transmit its data.

The main advantage of LEACH is that it outperforms conventional communication protocols, in terms of energy dissipation, ease of configuration, and system lifetime/quality of the network [59]. Providing such a low energy, wireless distributed protocol will help pave the way in a WSN. However, LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. So it is not recommended for large networks. Furthermore, the dynamic clustering may results to extra overhead.

PEGASIS & Hierarchical-PEGASIS: Power-Efficient GAthering in Sensor Information Systems (PEGASIS) [11] is an improvement of the LEACH protocol. Rather than forming multiple clusters, PEGASIS forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). Gathered data moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way.

Hierarchical-PEGASIS [11] is an extension to PEGASIS, which aims at decreasing the delay incurred for packets during transmission to the base station and proposes a solution to the data gathering problem by considering energy × delay metric. In order to reduce the delay in PEGASIS, simultaneous transmissions of data messages are pursued. To avoid collisions and possible signal interference among the sensors, CDMA and spatial separation approaches have been used.

Threshold sensitive Energy Efficient sensor Network protocol: TEEN [3] is responsive to sudden changes in the sensed attributes such as temperature. Responsiveness is important for time-critical applications, in which the

network operated in a reactive mode. The sensor network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until base station (sink) is reached.

After the clusters are formed, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for sensed attributes. Hard threshold is the minimum possible value of an attribute to trigger a sensor node to switch on its transmitter and transmit to the cluster head. Once a node senses a value at or beyond the hard threshold, it transmits data only when the value of that attributes changes by an amount equal to or greater than the soft threshold. As a consequence, soft threshold will further reduce the number of transmissions. However, TEEN is not good for applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) [4] is an extension to TEEN and aims at both capturing periodic data collections and reacting to time-critical events. The architecture is same as in TEEN.
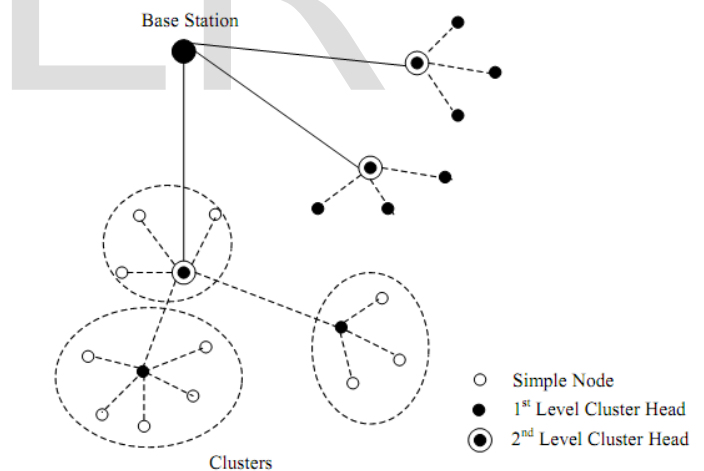

Fig5- Hierarchical Clustering in TEEN & APTEEN

APTEEN supports three different query types: historical, to analyze past data values; one-time, to take a snapshot view of the network; and persistent to monitor an event for a period of time. Simulation of TEEN and APTEEN has shown them to outperform LEACH [4]. The main drawbacks of the two approaches are the overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute-based naming of queries.

4   Location-based protocols

Most of the routing protocols for sensor networks require location information for sensor nodes. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way. Some of the protocols discussed here are designed primarily for mobile ad hoc networks and consider the mobility of nodes during the design [13][14][15]. However, they are also well applicable to sensor networks where there is less or no mobility.

Minimum Energy Communication Network: MECN [14] sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS. Although, the protocol assumes a mobile network, it is best applicable to sensor networks, which are not mobile. A minimum power topology for stationary nodes including a master node is found. MECN assumes a master-site as the information sink, which is always the case for sensor networks. It identifies a relay region for every node. The relay region consists of nodes in a surrounding area where transmitting through those nodes is more energy efficient than direct transmission. The main idea of MECN is to find a sub-network, which will have less number of nodes and require less power for transmission between any two particular nodes. In this way, global minimum power paths are found without considering all the nodes in the network. This is performed using a localized search for each node considering its relay region.

Geographic Adaptive Fidelity: GAF [13] is an energy-aware location-based routing algorithm designed primarily for mobile ad hoc networks, but may be applicable to sensor networks as well. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. It forms a virtual grid for the covered area. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. Nodes associated with the same point on the grid are considered equivalent in terms of the cost of packet routing. Such equivalence is exploited in keeping some nodes located in a particular grid area in sleeping state in order to save energy. Thus, GAF can substantially increase the network lifetime as the number of nodes increases. Nodes change

states from sleeping to active in turn so that the load is balanced. In order to handle the mobility, each node in the grid estimates its leaving time of grid and sends this to its neighbors. The sleeping neighbors adjust their sleeping time accordingly in order to keep the routing fidelity. Before the leaving time of the active node expires, sleeping nodes wake up and one of them becomes active. GAF is implemented both for non-mobility (GAF-basic) and mobility (GAF-mobility adaptation) of nodes.
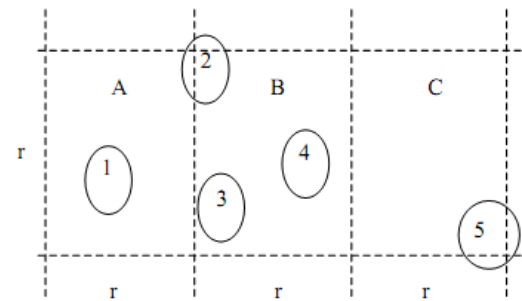

Fig6 - Virtual grid in GAF

There are three states defined in GAF. These states are discovery, for determining the neighbors in the grid, active reflecting participation in routing and sleep when the radio is turned off. Which node will sleep for how long is application dependent and the related parameters are tuned accordingly during the routing process.
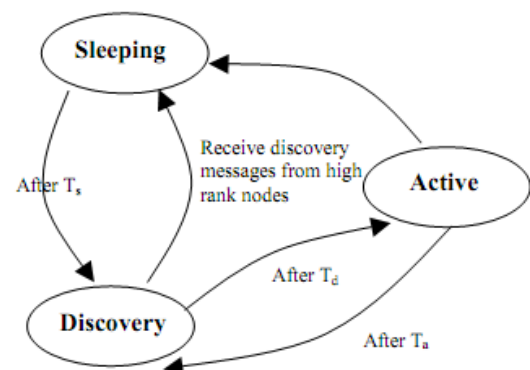

Fig7 – State transition in GAF

Simulation results show that GAF performs at least as well as a normal ad hoc routing protocol in terms of latency and packet loss and increases the lifetime of the network by saving energy. Although GAF is a location-based protocol, it may also be considered as a hierarchical protocol, where the clusters are based on geographic location. For each particular grid area, a representative node acts as the leader to transmit the data to other nodes. The leader node

however, does not do any aggregation or fusion as in the case of other hierarchical protocols discussed in this paper.

Geographic and Energy Aware Routing: GEAR [15], uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the target region. The idea is to restrict the number of interests in Directed Diffusion by only considering a certain region rather than sending the interests to the whole network. GEAR compliments Directed Diffusion in this way and thus conserves more energy.

In GEAR, each node keeps an estimated cost and a learning cost of reaching the destination through its neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. A hole occurs when a node does not have any closer neighbor to the target region than itself. If there are no holes, the estimated cost is equal to the learned cost. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted.

5   Conclusion

Since the radio transmission and reception consumes a lot of energy, one of the important issues in wireless sensor network is the inherent limited battery power within network sensor nodes. Therefore, battery power is crucial parameter in the algorithm design to increase lifespan of nodes in the network. In addition to maximizing the lifespan of sensor nodes, it is preferable to distribute the energy dissipated throughout the wireless sensor network in order to maximize overall network performance. Much research has been done in recent years, investigating different aspects like, low power protocols, network establishments, routing protocol, and coverage problems of wireless sensor networks. There are various routing protocols like location-aided, multi-path, data-centric, mobility-based, QoS based, heterogeneity-based, hierarchical routing, hybrid routing, etc., in which optimal routing can be achieved in the context of energy.

In this paper I have surveyed and summarized recent research works focused mainly on the energy efficient hierarchical cluster-based routing protocols for WSNs. As this is a broad area, this paper has covered only few sample of routing protocols. The protocols discussed in this paper have individual advantages and pitfalls. For realization of

sensor networks, it is needed to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, topology change, environment, and power consumption. Since these constraints are highly stringent and specific for sensor networks, new wireless ad hoc networking techniques are required to be explored further. There is still much work to be done in the area of protocols for wireless sensor networks.

REFERENCES

[1] J. Kulik, W. R. Heinzelman, and H. Balakrishnan, "Negotiation-based protocols for disseminating information in wireless sensor networks," Wireless Networks, Volume: 8, pp. 169-185, 2002.

[2] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed diffusion: a scalable and robust communication paradigm for sensor networks," Proceedings of ACM MobiCom '00, Boston, MA, 2000, pp. 56-67.

[3] A. Manjeshwar and D. P. Agarwal, "TEEN: a routing protocol for enhanced efficiency in wireless sensor networks," In 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, April 2001.

[4] A. Manjeshwar and D. P. Agarwal, "APTEEN: A hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks," Parallel and Distributed Processing Symposium., Proceedings International, IPDPS 2002, pp. 195-202.

[5] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-E±cient Communication Protocol for Wireless Microsensor Networks," Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS '00), January 2000.

[6] P. Agarwal and C. Procopiuc, "Exact and approximation algorithms for clustering," in Proc. 9th Annual. ACM-SIAM Symp. Discrete Algorithms, Baltimore, MD, Jan. 1999, pp. 658–667.

[7] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," In Proc. 33rd Hawaii International

Conference on System Sciences, HI, USA, 2000, Vol. 8, pp. 110.

[8] M. J. Handy, M. Haase, D. Timmermann, "Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection," In Proc. 4th International Workshop on Mobile and Wireless Communications Network, USA, 2002, Vol. 1, pp. 368-372.

[9] S. Hedetniemi, A. Liestman, "A Survey of Gossiping and Broadcasting in Communication Networks," book: Networks, 1998, Vol. 18, Issue 4, pp. 319-349.

[10] H. Lim, C. Kim, "Flooding in Wireless Ad Hoc Networks," Computer Communications, 2001, Vol. 24, Issue 3, pp. 353-363.

[11] S. Jung, Y. Han, T. Chung, "The Concentric Clustering Scheme for Efficient Energy Consumption in the PEGASIS," In Proc. 9th International Conference on Advanced Communication Technology, Gangwon-Do, 2007, Vol. 1, pp. 260-265.

[12] D. Braginsky and D. Estrin, "Rumor Routing Algorithm for Sensor Networks," in the Proceedings of the First Workshop on Sensor Networks and Applications (WSNA), Atlanta, GA, October 2002.

[13] V. Rodoplu and T.H. Ming, "Minimum energy mobile wireless networks," IEEE Journal of Selected Areas in Communications, Vol. 17, No. 8, pp. 1333-1344, 1999.

[14] L. Li and J. Y Halpern, "Minimum energy mobile wireless networks revisited," in the Proceedings of IEEE International Conference on Communications (ICC'01), Helsinki, Finland, June 2001

[15] B. Nath and D. Niculescu, "Routing on a curve," in HOTNETS 1, Princeton, NJ, October 2002.

_____

- *Sandeep Sharma is currently pursuing masters degree program in Computer Science and engineering in Rajiv Gandhi Technical University, MP, India. E-mail:s sandeepsharmasir@gmail.com*