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A SURVEY ON CONNECTIVITY MONITORING AND MAINTENANCE FOR WIRELESS SENSOR NETWORKS

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ABSTRACT: Wireless Sensor Networks (WSNs) has a wide variety of applications such as Healthcare, home security, biological detection and battlefield surveillance. It has brought new challenges to the researcher of network protocols. One fundamental problem in wireless sensor networks is the connectivity issue, which reflects how best a network is connected or linked to each other by sensors and also needs to be ensured so that the sink sensor node receives all sensed data for further processing. It is very important to have full connectivity in a WSN, after it is deployed and also to maintain the same. But, these networks are restricted by the low user-to-node ratio, energy constraint and bandwidth resources, and frequent failure due to problems of energy, vulnerability to attack and they also put on them lots of bottlenecks that make issues in wireless sensor networks very challenging. In this survey, we present our investigation of various connectivity problems for maintain and monitoring approaches used by various algorithms to achieve connectivity. Our survey attempts to presents an outlook of these problems as well as the solutions proposed in recent research literature.

Keywords: Networks, monitoring, maintenance, connectivity, density control, QoS.

1. INTRODUCTION

1.1. Goal: Sensor Network Connectivity

An important problem addressed in literature is the Sensor Connectivity Problem. i.e. In sparse distribution of sensor nodes, multi-hop routing is normally used to transfer the message from a source node to a destination node. A problem with this method is that loss of connectivity of sensor nodes in the link between source node and destination node may lead to a partitioning of the WSN. The connectivity, i.e., the quality of communication channels in between individual nodes is vital to allow for sensor data retrieval. One important issue that arises in such high-density WSN is density control – the function density controls the density of the working nodes to certain extent. It ensures only a subset of nodes works in the active mode, while fulfilling the following two important requirements: (i) Coverage: the area that can be monitored is not smaller than that which can be monitored by a full set of sensors; and (ii) connectivity: the sensor network remains connected so that the information collected by sensor nodes can be relayed back to data sinks or controllers.

Connectivity and coverage problems are caused by the limited communication and sensing range. To solve these two problems the solution lies in how the nodes are placed with reference to each others. Coverage problem is regarding how to ensure that each and every point in the region to be observed & monitored is covered by the sensor nodes and in case of connectivity, the sensors need to be positioned very close to each other so that they are within each other communication range & there by connectivity is established.

The connectivity problems are addressed by several authors and several protocols have been proposed in the literature to maintain the network connected [1, 2, 3]. Many connectivity maintenance protocols in this literature, e.g., [3, 4, 5], use the deterministic connectivity model, because it has the advantage of facilitating in the design and performance analysis of the protocols. By depending on the deterministic connectivity model, may lead to incorrect operation of these protocols in real environments. In addition, these protocols fail to provide any assessment of the quality of communication between nodes.

2. PRELIMINARIES

2.1. Connectivity

A wireless Sensor Network (WSN) is considered to be connected when at least one single link is established between each pair of nodes in the network. Connectivity depends mainly on the existence of link. It is affected by changes in network topology due to mobility, the failure of sensor nodes and attacks and so on. The consequences of such occurrences include the loss of paths, the isolation of nodes, the upgrading of paths, the partitioning of the network and re-routing.

Connectivity can be modeled as a graph G (V, E) where the set of vertices (Sensor nodes) is denoted by "V" and "E"

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the set of edges (links). This graph is termed to be k-connected if there are at least “k” disjoint links between every pair of sensor nodes u, v $\in$ V. Connectivity is termed as QoS i.e. as measure of fault tolerance or diversity of paths in the wireless sensor network. The need for k-connectivity of the network graph is a fundamental condition of it being operational where k = 1. In general, the connectivity of a sensor network can be expressed by the relation. [6].

$$\mu(R) = \frac{n\pi R^2}{A} \quad (1)$$

Where R is the radius of transmission, N the number of nodes is denoted by “N” in the area A and the area is given by “A” and The authors [7] have shown that when connectivity $\mu(R)$ reaches Six sensor nodes, the probability that a node is connected tends to Unity, i.e. that the network forms a connected graph.

3. RELATED WORK

The author [8] in Geographical Adaptive Fidelity (GAF) protocol presents how to extend the network lifetime by turning off the unwanted sensor nodes while keeping the same status of routing fidelity, which is defined as uninterrupted, undisturbed connectivity between communicating sensor nodes. GAF imposes a grid on the sensor network and sensor nodes in the same virtual grid coordinate with one another to decide which node should go on sleep and its duration of sleep.

In [9], presents a connectivity-maintaining protocol SPAN, which can puts off all unwanted sensor nodes such that all other active nodes are connected via communication links and all unwanted sensor nodes are directly linked to at least one active sensor node. Maintaining a network connected is also a fundamental obligation of works results at topology control, which is to adjust sensors nodes’ transmitting power for energy efficiency and by avoiding collision [10, 11, 12].

[13] Presents a coverage algorithm by studying at how intersection levels between sensors’ sensing ranges are covered by their neighboring sensor nodes, and presents that coverage can establishes the connectivity as long as sensors’ communication ranges are more than twice their sensing ranges R_s.

A Coverage Configuration Protocol (CCP), that can results different degrees of coverage and also maintains connectivity. If the communication ranges are less than the double the sensing ranges R_s, [13] presents to sum up Coverage Configuration Protocol (CCP), with SPAN [9] to give both sensing coverage and also connectivity. [14], presents the protocol OGDC (Optimal Geographical Density Control). According to the authors, this is a full distributed and local search algorithm based on the following: if the communication (or radio) range is at least twice of the sensing range, then a complete coverage of a convex area implies the connectivity among the working set of nodes.

In [15], the authors present cooperative transmission to increase the connectivity, the disconnected parts of a WSN which had the disadvantage of the separation issue of multi-hop sensor networks. This approach gives better connectivity over 50% compared to multi-hop method with decreased number of nodes required to result in full coverage of an area up to 30%.

It is easy to implement and without routing tables. It can be used as a fall-back solution in Wireless Sensor Network. The sensor network does this cooperative transmission when sensor nodes find themselves not connected. In sparse settings, this Cooperative transmission can improve the connectivity of sensor nodes toward other access point.

4. CONNECTIVITY MONITORING

In Wireless sensor network, Connectivity monitoring is an important management tasks. The network connectivity information provides important support for debugging and root-cause analysis. In [16], the authors proposed a network debugging system called Sympathy. This requires connectivity details from the nodes for root-cause analysis. The authors simply assume that each and every node periodically transmits its neighbor table to central controller. Since the test bed on which this experiment was carried out was small, this was not a serious issue. In [17], the authors presented a protocol that each sensor node locally monitors its k-hop neighbors and the neighborhood information aggregates along the path to the central controller. This work utilized the bitmap structure and is only applicable to a relatively very small sensor network.

In [18], the authors presented Top Disc (TD) algorithm for wireless sensor networks with its applications to network management system. The idea of the algorithm is to find a set of distinguished nodes (Minimum Dominating Set-MDS), using their neighborhood information to build the tentative topology of the sensor network. In graph theory, a dominating set for a graph G = (V, E) is a subset D of V such that every vertex not in D is joined to at least one member of D by some edge. The problem of finding the minimum dominating set (MDS) is NP-complete. Top Disc is an algorithm for distributive minimum dominating set (MDS) election based on the idea of sensor node coloring. Only those sensor nodes in MDS will communicate back to the topology discovery problems and hence from there to reduce the communication overhead of the process.

STREAM [19, 20] is a multi-resolution topology recollecting protocol which does the tradeoffs between topology details and resources expended. This algorithm makes use of Minimal Virtual Dominating Set (MVDS) to explain the distinguished sensor nodes that will response the topology problems. The building of MVDS relies on the concept of virtual radius, which explains a set of virtual neighbors that are inside the virtual radius of each sensor node. By varying the virtual radius, the Minimal Virtual Dominating Set (MVDS) of different resolution can be built, and the multi-resolution topology retrieval can be made.

In [21], the problem of complete topology discovery work is depends on the assumption that location information is presently available. The neighborhood pattern is also assumed that they have very good correlation with the distance between a pair of nodes. By making use of this assumption, the cost of topology recollection can be much reduced. Cooperative Transmission to Increase the Connectivity.

5. MICROSCALE CONNECTIVITY MONITORING

In sensor networks it is observed in [22] that connectivity statistics can be used to compute mean topological density and to study the impact of link asymmetry and also to study the geographical routing algorithms, and to assess behaviors of algorithms that depend on spatial correlation.

The complete wireless sensor network connectivity graph is formed by aggregating the neighbor tables (Microscale Connectivity Information) of all the sensor nodes in the region of interest. Microscope connectivity monitoring (MCM) is an important management task in networks. But getting the local connectivity information efficiently in WSN is generally a hard problem.

Connectivity is highly unpredictable because of the energy constraint in nodes, lower power transmission, deployment methods other related factors in the environment.

The authors presented a Hop-count and Hashing-based Connectivity Monitoring (H^2CM) algorithm, efficient and a flexible algorithm to get connectivity link of the sensor nodes located in the monitored nodes. This algorithm is flexible; in this each and every node can be individually configured to get the expected level of accuracy. The advantage of this algorithm is very efficient in reducing communication cost, even when accurate & full connectivity information is expected.

In the fast changing scenario, the connectivity of wireless links changes with respect to the time, the sensor nodes also needs to transfer the information to the centrally situated controller either on demand or at regular interval through multiple hops. The cost can be high, due to the bandwidth and energy constraint and resources available on the nodes.

H^2CM is based on a divide and-conquer approach. In this several techniques are combined to work with different types of sensor network and neighbor set sizes. These methods are (1) hop count filtering, (2) Bloom filter and (3) use of a single hash value as checksum. By changing the amount of information swapped, this algorithm is able to give various levels of accuracy in connectivity information.

6. CRITICAL TOTAL POWER FOR MAINTAINING K-CONNECTIVITY

An alternate method to prolong network lifetime in WSN is to reduce the transmission power since the transmission power leads for a large amount of power consumption of wireless sensors [23]. Reducing transmission power not only saves power, but also decreases MAC-level collision and thereby improves network capacity and performance. However, to maintain proper network performance, it is also essential to guarantee the network connectivity. In many cases it is important that the networks are k-connected for the sake of robust and fault tolerant communications.

Several researchers studied the minimum node degrees that ensure network connectivity or k-connectivity. In [24] proved that in a random ad-hoc sensor network with n nodes, each node should be connected to Θ (log n) nearest neighbor node in order that the connectivity is ensured in the asymptotic sense. Authors showed that if each node connects with less than 0.074 log n nearest neighbors, the network is asymptotically disconnected with probability approaching unity as n goes to infinity, while if each node connects with more than 5.1774 log n nearest neighbors then the network is asymptotically connected with probability approaching unity.

In [25], authors showed that for any given $k \geq 1$ and any real number $\alpha > 1$, if every node connects with at least αe log n neighbors (where $e \approx 2.718$ is the natural base); the network is normally connected / k-connected with probability approaching unity.

7. TIMING AND RADIUS CONSIDERATIONS FOR MAINTAINING CONNECTIVITY

In this [26] proposed an algorithm in order to maintain the connectivity of the sensor nodes and they vary the radius and as well as timing parameters of the sensing coverage scheme to achieve the best QoS. In addition to this, to check the lifetime of the network after making the necessary changes in power. The methodology specifically designed in order to manage connectivity have been studied in the literature, no work till the date has checked the connectivity issues of a sensing maintenance protocol working under the limitation of equation 1.

$$Radius_{transmission} > 2 * Radius_{sensing} \quad (1)$$

When $R_t > R_s$, does not hold i.e., connectivity is not automatically established by the sensing the coverage component, then both sensing and also routing coverage must be maintained separately.

The methodology explained here can also be used in this case by considering two instances of the same protocol. Firstly, instance maintains the required density using the sensing radius (R_s) and secondly, instance is provided with a sensing range (R_s) of half the transmission radius (R_t).

7.1. TIMING CONSIDERATIONS

In first method, a sleep time of longer duration would conserve good amount of energy for the nodes and potentially increase the working time of the network. Whereas with a short sleep time, the topology of the sensor network can be very dynamic, this may be problematic for routing information and due to which the receiving station may not receive the messages.

7.2. Radius Considerations

A second method is available to adjust the working of a connectivity maintenance protocol, by regulating the density of active sensor nodes through a radius value of suitable length.

By conservatively giving the transmission radius for a sensor node, a denser than necessary topology is produced which results to more redundancy and strengthens to cope better with failed sensor nodes.

8. DENSITY CONTROL

Reducing energy consumption and maximizing the system lifetime has been a major design issue for wireless sensor networks. An important way of minimizing energy in the network at low level, to put unwanted nodes to sleep and thereby, control the "density" of the remaining active nodes at an adequate, low level.

9. DENSITY CONTROL FOR MAINTAINING CONNECTIVITY

Most of the researchers are working towards the density control for maintaining connectivity in WSNs. Geographical Adaptive Fidelity (GAF) [27] defines that each & every node is aware of its geographical location and conserves power by dividing a monitoring region of interest into rectangular virtual grids. Each and every node is associated with one particular rectangular grid based on its local information. The size of grid is small enough; thereby any sensor node can communicate directly with any other nodes within its adjacent cells. By keeping the maximum distance between any pair of sensor nodes in neighbor grids is below the transmitting range of each other. This restriction puts that a sensor node can communicate with its neighboring grids. Out of these sensor nodes a leader-node is then elected within each grid to remain awake and relay packets, whereas all the other sensor nodes are put into sleep. The leader-node election protocol in each grid takes into account of power usage at each sensor node.

SPAN [28] is a distributed and randomized protocol. In this protocol sensor nodes make local decisions. They decides on whether they should go sleep or to be active condition as forwarding agency. Sensor Nodes that opt to stay active/awake and to maintain sensor network connectivity are termed as coordinators. A non-coordinator sensor node elects itself as a coordinator, only when two of its neighbors are not in a position to communicate with each other indirectly or directly through its coordinators. The non-coordinator sensor node shows its willingness by announcing by being a coordinator via its local broadcast system, delaying by a gap that reflects the available energy of a node. The information required for the election of coordinator is swapped among all the neighbors via HELLO messages.

LEACH [29] is a self-organizing, clustering-based protocol, which is used in Wireless sensor networks. The operation is divided into rounds and a single round is composed into two phases and they are termed as setup phase and secondly the steady phase. During the setup phase, Clusters are formed and mechanisms are derived to rotate the role of cluster head (CH) among sensor nodes to uniformly distribute the power load. In the steady phase, LEACH employs time-division multiple access (TDMA) for in between-cluster communication between the sensor nodes and the cluster-head. Each wireless sensor node in a cluster can transmit only in on the predefined time-schedule within each frame and it can sleep in remaining other time slots.

The [30] proposed a distributed connectivity maintenance protocol to ensure a given target path quality between the sensor nodes and hence it can be used for critical applications such as backbone construction [31] in large-scale networks, where a subset of sensor nodes are selected to give data from the entire network.

This protocol is simple to implement, and also the author demonstrated its robustness against random node failures, problems in node locations, and incorrect time synchronization of nodes using extensive simulations. The proposed protocol minimizes the number of activated nodes and intern the network consumes much less energy than other protocols in the literature.

In [32], the authors proposed the protocol called Probabilistic Connectivity Maintenance Protocol (PCMP). The goal of PCMP is to initialize a subset of deployed nodes such that the probability of delivering packets between any arbitrary nodes in the network is at least "α", i.e., keep the network "α", connected. To achieve this result, the protocol initializes the nodes to form an approximate triangular mesh. The distance between nodes in the triangular mesh is computed to reach the target sensor network delivery rate. The Probabilistic Connectivity Maintenance Protocol shows that networks using integrated PCMP protocol have substantially improved lifetime compared with SPAN, GAF and CCP-SPAN.

10. CONCLUSION

Most of the research works are in progress mainly on coverage issues only. But without connectivity, coverage is useless in presenting the Wireless sensor network. The connectivity problem is very much concerned in the field of wireless communication. In this survey paper, we reviewed major connectivity issues in WSNs, namely connectivity maintenance and Monitoring and surveyed various methods and protocols to monitor and also to maintain the connection, under this frame work, we listed, reviewed and compared some research works in the field. Our aim is to present both a general overview of connectivity issues in wireless sensor network and give the important citations such that further review of the relevant literature survey can be done by the interested researcher.

REFERENCES

[1] Alberto Cerpa and Deborah Estrin., "ASCENT: Adaptive Self-Configuring Sensor Networks Topologies", IEEE Transactions on Mobile Computing, pp. 272-285, 2004.

[2] Benjie Chen, Kyle Jamieson, Hari Balakrishnan, and Robert Morris., "SPAN: An Energy Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks", Wireless Networks, pp. 481-494, 2002.

[3] F. Dai and J.Wu., "An Extended Localized Algorithm for Connected Dominating Set Formation in Ad Hoc Wireless Networks", IEEE Transactions on Parallel and Distributed Systems, pp. 908-920, 2004.

[4] Ya Xu, John Heidemann, and Deborah Estrin., "Adaptive Energy-Conserving Routing for Multihop Ad Hoc Networks", Research Report 527, USC/Information Sciences Institute. Available at: http://www.isi.edu/johnh/PAPERS/Xu00a.html, October 2000.

[5] Ya Xu, John Heidemann, and Deborah Estrin., "Geography-Informed Energy Conservation for Ad Hoc Routing", In Proceedings of the ACM international Conference on Mobile Computing and Networking, Rome, Italy, pp. 70-84. July 2001.

[6] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cyirci, "Wireless Sensor Networks: A Survey", Computer Networks, 38, No. 4, pp. 393-422, 2002.

[7] L. Kleinrock and J. Silvester., "Optimum Transmission Radio for Packet Radio Networks or Why Six is a Magic Number", In National Telecommunications Conference, Birmingham, Alabama, pp. 4.3.2–4.3.5, December 1978.

[8] Xu, Y., Heidemann, J., and Estrin, D., "Geography-Informed Energy Conservation for Ad Hoc Routing", In ACM International Conference on Mobile Computing and Networking, pp.70-84, 2001.

[9] Chen, B., Jamieson, K., Balakrishnan H., and Morris., "SPAN: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks", ACM Wireless Networks, pp. 481–494, Sep. 2002.

[10] Burkhart M., Vonrickenbach, P., Wattenhofer, R., & Bollinger, A., "Does Topology Control Reduce Interference?", In ACM International Symposium on Mobile Ad Hoc Networking and Computing, pp. 9-19, 2004.

[11] Li, N. & Hour, J. C., "FLSS: A Fault-Tolerant Topology Control Algorithm for Wireless Networks", In proceedings of the ACM International Conference on Mobile Computing and Networking, 2004.

[12] Wattenhofer, R., Li, L., Bahl, P., & Wang, Y.-M. 2001., "Distributed Topology Control for Power Efficient Operation in Multihop Wireless Ad Hoc Networks", In IEEE INFOCOM, pp.1388-1397.

[13] Wang, X., Xing, G., Zhang, Y., Lu, C., Pless, R.,& Gill, C., "Integrated Coverage and Connectivity Configuration in Wireless Sensor Networks", In ACM Int'l Conf. on Embedded Networked Sensor Systems (SenSys), pp. 28-39. 2003.

[14] Zhang, H.and Hou, J. C., "Maintaining Sensing Coverage and Connectivity in Large Sensor Networks", In NSF International Workshop on Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Wireless, and Peer-to-Peer Networks, 2004a.

[15] Albert Krohn, Michael Beigl, Christian Decker, David Garc´es Verona, "Increasing Connectivity in Wireless Sensor Network using Cooperative Transmission", http://www.rfm.com.

[16] Nissanka B. Priyantha, Anit Chakraborty, and Hari Balakrishnan., "The Cricket Location-Support System", In the ACM Annual International Conference on Mobile Computing and Networking (MobiCom), 2000.

[17] Warren Robak. Futureworld: Sensors for Soil, Air, Everywhere. http://www.universityofcalifornia.edu/news/article/9729.

[18] Budhaditya Deb, Sudeept Bhatnagar, and Badri Nath., "Multiple-Resolution State Retrieval in Sensor Networks", In the IEEE Workshop on Sensor Network Protocols and Applications (SNPA).

[19] Mark de Berg, Marc van Kreveld, Mark Overmars, and Otfried Schwarzkopf., "Computational Geometry: Algorithms and Applications", Springer, 1997.

[20] Budhaditya Deb, Sudeept Bhatnagar, and Badri Nath., "A Topology Discovery Algorithm for Sensor Networks with Applications to Network Management", In the IEEE CAS Workshop on Wireless Communications and Networking, 2002.

[21] Honghai Zhang and Jennifer C. Hou., "Maintaining Sensing Coverage and Connectivity in Large Sensor Networks", International Journal of Wireless Ad Hoc and Sensor Networks, 1(1-2): pp. 89-124, 2005.

[22] Larry Carter, Robert Floyd, John Gill, George Markowsky, and Mark Wegman., "Exact and Approximate Membership Testers", In the Annual ACM Symposium on Theory of Computing (STOC), 1978.

[23] L. Li, J. Halpern, V. Bahl, Y.M. Wang, and R. Wattenhofer., "Analysis of a Cone-Based Distributed Topology Control Algorithm for Wireless Multi-Hop Networks", In Proceedings of ACM Symposium onPrinciple of Distributed Computing (PODC), pp. 264-273, 2001.

[24] F. Xue and P.R. Kumar., "The Number of Neighbours Needed for Connectivity of Wireless Networks", Wireless Networks, 2003. URL:http://decision.csl.uiuc.edu/ prkumar.

[25] P-J. Wan and C. Yi., "Asymptotic Critical Transmission Radius and Critical Neighbor Number for k-Connectivity in Wireless Ad Hoc Networks", In the ACM Annual International Conference on Mobile Computing and Networking, 2004.

[26] Richard Tynan, G.M.P. O'Hare, Michael J. O'Grady, Conor Muldoon, "Timing and Radius Considerations for Maintaining Connectivity QoS", Eleventh International Conference on Mobile Data Management, IEEE Computer Society, pp. 419-426, 2010.

[27] Y. Xu, S. Bien, Y. Mori, J. Heidemann, and D. Estrin,. "Topology Control Protocols to Conserve Energy in Wireless Ad Hoc Networks", In CENS Technical Report 0006, January 2003.

[28] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris,. "Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks", In Proceedings of ACM/IEEE International Conference on Mobile Computing and Networking, Rome, Italy, pp. 85-96 July 2001.

[29] W.R. Heizelman, A. Chandrakasan, and H. Balakrishnan, "Energy SPAN: Efficient Communication Protocol for Wireless Micro Sensor Networks", IEEE Proceedings of the Hawaii, International Conference on System Sciences, January 2000.

[30] Mohamed Hefeeda and Hossein Ahmadi, "An Integrated Protocol for Maintaining Connectivity and Coverage under Probabilistic Models for Wireless Sensor Networks", Ad Hoc & Sensor Wireless Networks, 7, pp. 295-323, 2009. Old City Publishing, Inc.

[31] D. Simplot-Ryl, I. Stojmenovic, and J.Wu., "Energy-Efficient Backbone Construction, Broadcasting, and Area Coverage in Sensor Networks", In I. Stojmenovic, editor, Handbook of Sensor Networks: Algorithms and Architectures, John Wiley & Sons, Inc, pp. 343-379, 2005.

[32] Hussein Ahmadi, "Probabilistic Coverage and Connectivity in Wireless Sensor Networks", Sharif University of Technology, Tehran, Iran, 2005.