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TOPOLOGY CONTROL ISSUES IN WIRELESS SENSOR NETWORKS (WSN) FOR INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

R. Ramya[1], G. Saravanakumar[2] and S. Ravi[1]
[1]Department of Electronics and Communication Engineering, Dr M.G.R Educational and Research Institute University, Chennai, India
[2]Department of Electronics and Communication Engineering, Vel Tech High Tech Dr.Rangarajan Dr.Sakunthala Engineering College, Chennai, India
E-Mail:ramyarajarathinam@yahoo.com

ABSTRACT

Topology issues have received more and more consideration in Wireless Sensor Networks (WSN). While WSN applications are generally optimized by the given underlying network topology, another trend is to optimize WSN by means of topology control. A number of approaches have been identified in this area, such as topology directed routing, cooperating schemes, sensor coverage based topology control and network connectivity based topology control. A good number of the methods have proven to be able to offer an improved network topology for traffic monitoring and communication concert for intelligent transportation systems with extended system lifetime. In this paper, we present a full analysis of the studies in this area.

Keywords: intelligent transportation systems, wireless sensor networks, topology, sensor holes, power control, power management.

1. INTRODUCTION

Intelligent transportation systems (ITS) are advanced applications which, without embodying intelligence as such, aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks. ITS as systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport [1]. Many of the proposed ITS systems also involve surveillance of the roadways, which is a priority of homeland security [2]. Funding of many systems comes either directly through homeland security organisations or with their approval. Further, ITS can play a role in the rapid mass evacuation of people in urban centres after large casualty events such as a result of a natural disaster or threat. Much of the infrastructure and planning involved with ITS parallels the need for homeland security systems [3]. Intelligent transport system is shown in Figure-1.

Figure-1. Intelligent Transport System.

In the developing world, the migration from rural to urbanized habitats has progressed differently. Many areas of the developing world have urbanised without significant motorisation and the formation of suburbs. A small portion of the population can afford automobiles, but the automobiles greatly increase congestion in these multimodal transportation systems. They also produce considerable air pollution, pose a significant safety risk, and exacerbate feelings of inequities in the society. High-population density could be supported by a multimodal system of walking, bicycle transportation, motorcycles, buses, and trains.

Wireless Sensor Networks (WSNs) have turn into an emerging technology [1] that has a wide range of potential applications including environment monitoring, object tracking, scientific observing and forecasting, traffic control and etc. A WSN normally consists of a large number of distributed nodes that organize themselves into a multi-hop wireless network and typically these nodes coordinate to perform a common task. Architecture of Wireless Sensor Networks is shown in Figure-2.

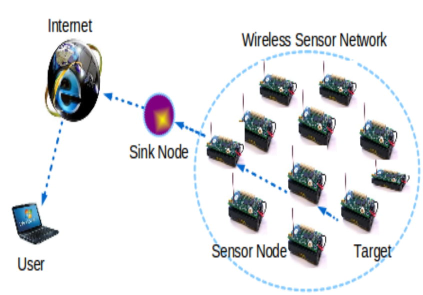

Figure-2. Wireless Sensor Network.

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To achieve a lasting and scalable WSN design, the following aspects have to be carefully taken into account in the design stage:

- Energy conservation.
- Limited bandwidth.
- Unstructured and time-varying network topology.
- Low-quality communications.
- Operation in hostile environments.
- Data processing.
- Scalability.

Quite a few solutions have been planned in the text which addresses at least some of the above issues. In exacting, huge efforts have been dedicated to the design of energy efficient message delivery and data retrieving methods. With the attentiveness of the basic network topology, more efficient routing or broadcasting schemes could be achieved. Furthermore, the network topology in WSNs can be misused by varying the nodes' transmitting range and adjusting the wake/sleep schedule of all nodes. Therefore, further energy can be saved if the network topology can be maintained in an optimal manner [4].

In this study, in section 1 we focus on wireless sensor networks application to intelligent transportation system and topology control. Section 2 we study and analyze topology control issues followed by section 3 topology awareness problems. In Section 4, we introduce existed topology control approaches for both sensor coverage topology and sensor connectivity topology. The article concludes in Section 5 with a summarization of the study of Topology Control Issues in Wsn for ITS and further outline the future of research directions.

1.1 Key technologies of wireless sensor network application in the transportation systems and topology control

With the deepening of the research, many key technologies are handled well, which leads to the large-scale application of WSN for intelligent transportation systems.

The role of logistics in social and economic development is becoming increasingly prominent. Through a variety of advanced modem logistics technology to promote the development of logistics has very important practical significance. The WSN has application value in many fields of logistics, including equipment monitoring, warehouse environment monitoring, transportation vehicles in production logistics and tracking and monitoring of the goods, dangerous goods logistics management and the cold chain logistics management, etc.

1.1.1 Energy management

Because sensor networks node distribution are numerous with large coverage and complex working environment, to replace the battery is not realistic most of the time. In the current research progress of the problem of energy conservation, dormancy mechanism is one of the most effective ways to save energy.

1.1.2 Node location

No matter the sensor node is installed in the warehouse or in transport vehicle, the node localization is a key issue. Node localization refers to the determination of the relative position or absolute position of sensor nodes. At present there are mainly two types of node localization algorithm: localization algorithm based on distance measurement and localization algorithm which is not relates to distance measurement.

1.1.3 Mobile control problem

Motion control is responsible for the detection and control of mobile nodes and maintenance of routing to the rendezvous point and still makes the sensor nodes track its neighbors. Through topology control can automatically generates good network topology to improve the efficiency of routing protocol and MAC protocol, laying the foundation of data fusion, time synchronization, and the target location and many other aspects, to save energy of nodes to prolong the lifetime of the network.

1.1.4 MAC protocol

MAC protocol has important influence on energy consumption of nodes because of its direct control of radio frequency module which is the biggest energy component in the node. Therefore, the energy efficiency is the main design goal of MAC protocol of wireless sensor network. At present, the methods for reducing power consumption of the MAC protocols are mainly the reduction of data traffic, increase of the RF module sleep time and conflict avoidance, etc.

1.1.5 Routing protocol

The main task of the routing protocol is to establish a routing between sensor nodes and sink nodes and transfer data reliably. The first design principle is to save energy and prolong the network lifetime. Based on the above reasons, the protocol can't be too complicated and too much state information can't be saved in nodes, and it does not allow too many routing information exchange between nodes. At the same time sending redundant information should be avoid as much as possible and reduction of energy waste is required.

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1.1.6 Design of intelligent sensor

In order to reduce the workload of system design, abstract away the data model of part of the widely used sensors, design software and hardware of the system according to the abstracted structure.

The current commonly used sensors can be abstracted as analog input and digital input, and reverse control can be abstracted as analog output and digital output.

1.1.7 Artificial neural network data fusion technology

The basic principle of neural network fusion technology is similar to the human brain process of synthesizing data or information. When routing is without application of neural network fusion technology, there exits many redundant information transmission between sensor nodes in the network. This increases the node's working intensity, time of data processing and frequency of communication.

The application of neural network data fusion technology can greatly improve the intelligent level of sensor network applications, and reduce the node energy consumption and prolong the lifetime of sensor networks effectively.

1.2 Prospect analysis of application in wireless sensor network for transportation system

Wireless sensor network is made up of a large number of low-cost micro sensor nodes deployed in monitoring area. And it is a multiple hops self-organizing network system formed by wireless communication mode. Its purpose is collaboratively to perceive, collect and process perception object information in network coverage area and sent it to the observer. As wireless communication, embedded computing and sensor technology with proven methods of topology control increasingly mature, the research and application of WSNfor intelligent transportation system is becoming more and more widely.

A number of interesting and desired applications of Intelligent Transportation Systems (ITS) have been stimulating the development of a new kind of ad hoc network: Vehicular Ad Hoc Networks (VANets). In these networks, vehicles are equipped with communication equipment that allows them to exchange messages with each other in Vehicle-to-Vehicle communication (V2V) and also to exchange messages with a roadside network infrastructure (Vehicle-to-Roadside Communication-V2R).

Further more number of applications are envisioned for these networks, some of which are already possible in some recently designed vehicles:

- vehicle collision warning
- security distance warning
- driver assistance
- cooperative driving
- cooperative cruise control
- dissemination of road information
- Internet access
- map location
- automatic parking
- driverless vehicles

All of these applications require, or can take advantage of, some sort of localization technique. In the localization problem, the definition of a reference system among nodes is performed by identifying their physical location (e.g., latitude, longitude, and altitude) or their relative spatial distribution in relation to each other. For instance, Map Location is usually done using Global Positioning System (GPS) receivers with a Geographic Information System, while Vehicle Collision Warning Systems can be implemented by comparing distances between nodes' locations combined with geographic information dissemination.

As ITS and VANets technology advances toward more critical applications such as Vehicle Collision Warning Systems (CWS) and Driverless Vehicles, it is likely that a robust and highly available localization system will be required. Unfortunately, GPS receivers are not the best solution in these cases, since their accuracy range from up to 20 or 30 m and since they cannot work in indoor or dense urban areas where there is no direct visibility to satellites. For these reasons and, of course, for security reasons, GPS information is likely to be combined with other localization techniques such as Dead Reckoning, Cellular Localization, and Image/Video Localization, to cite a few. This combination of localization information from different sources can be done using such Data Fusion techniques as Kalman Filter and Particle Filter.

In this study, we analyze the localization requirements of a number of VANet applications. We then survey several proposed localization techniques that can be used to estimate the position of a vehicle, and we highlight their advantages and disadvantages when applied to VANets. However, that none of these techniques can achieve individually the desired localization requirements of critical VANet applications, we have to find how the localization information from multiple sources can be combined to produce a single position that is more accurate and robust is another area for researchers.

1.3 Location-aware VANet applications

Most VANet applications consider the availability of real-time updated position information. They differ, however, on the localization accuracy required in order to be able to function properly. For instance, some applications can work with inaccurate localization information in which computed positions can

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have errors from 10 to 20 or 30 m, while other applications, especially critical safety applications, require more accurate and reliable localization systems with sub-meter precision. In this section, we divide VANet applications into three main groups according to their localization requirements and show how position information is used by these protocols and algorithms.

1.4 Applications able to work with inaccurate localization

Although some VANet applications do not require any localization to function, most of them can take advantage of localization and show better performance when the position information of vehicles is available. Most of these applications are related to vehicle communication, which includes vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) communication, and provide services such as information routing, and the data dissemination of accidents, road congestion, etc. The algorithms that deal with communication will accept localization errors mostly within 10-20 or even 30 m, since the long transmission range of the vehicles' transmitters can compensate for these localization inaccuracies. However, the greater the localization error, the worse the algorithms' performance. In the following paragraphs we will discuss some of these applications and algorithms.

Routing protocols for VANets usually use position information in order to improve their performance and be able to comply with such VANets requirements as dynamic topology changes and frequent network fragmentation. This routing technique has long been used in Ad Hoc networks and most of its protocols can also be applied to VANets. A classical example is Greedy Forwarding and in which, location information is used at each step to forward a packet to the neighbor nearest to the destination node. However, some geographic routing protocols have also been designed specifically for VANets, taking advantage of more geographical knowledge such as Maps and movement information. Routing techniques are also used to access local infrastructured networks via an Internet connection these cases, position information as well as future trajectory knowledge can be used to assist routing.

Several Data Dissemination protocols and have been proposed for VANets that aim to inform both near and distant vehicles about transit conditions such as the road flow, congestion, and potentially dangerous situations. Most of these protocols also consider localization knowledge mostly to ensure that locally disseminated information reaches only the vehicles that should be interested in it. Driver direction can also be used, as proposed by the ODAM algorithm. known and already in-use driver assistance application is Map Localization, in which the current position of the vehicle is shown on a map. In these applications, a path direction between two points of the city, for instance, can be drawn on a map indicating the current location of the vehicle.

1.5 Applications requiring accurate localization

This kind of application requires a certain degree of confiability and accuracy in the computed positions and/or in the distance estimation between vehicles. Applications in this group are usually Cooperative Driving applications, where vehicles in a VANet exchange messages between them to drive and share the available space on the road cooperatively. In these applications, the vehicles can assume partial control over driving. In most cases, localization errors from 1 to 5 meters are acceptable. In the following paragraphs we will discuss some of these applications and algorithms.

In Cooperative Adaptive Cruise Control, the vehicle maintains the same speed whether traveling uphill or down without requiring driver intervention. Usually, the driver sets the speed and the system will take over, but in this case, vehicles can cooperate among themselves to set this speed adaptively. This application only takes care of speed, while the driver still has to control the direction of the vehicle.

Another interesting application of VANets is Cooperative Intersection Safety, in which vehicles arriving at a road intersection exchange messages in order to make a safe crossing besides ensuring a safe crossing, it is also possible to make a Blind Crossing, where there is no light control and the vehicles cooperate with each other to make a cooperative crossing. In these applications, the localization accuracy must allow the application to differentiate between the lanes as well as the sides of the street.

Vehicle Following or Platooning is a technique used to make one or more vehicles follow a leader vehicle to form a train-like system. This application can be useful in situations where two or more vehicles are going to the same location. A minimum distance must be ensured between vehicles. Also, vehicles must track the position of the vehicle in front of them with a good precision, both of which can be accomplished by a localization system with accurate position information.

1.6 Applications requiring high-accurate localization

A third class of applications for VANets requires very precise and reliable localization systems. Most of these applications are critical safety applications such as Vehicle Collision Warning Systems (CWS) and other driver assistance applications. In driver assistance applications, VANet resources are used to enhance the driver's perception and knowledge of the road and environment. In these applications, the driver is informed about the surrounding environment in order to improve safety, and, in case of emergency, the vehicle can perform some automatic procedures. These are the most interesting applications for VANets, and since we are dealing with

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safety, position information reliability and accuracy are crucial. Accurate positioning ensures localization with a meter or sub-meter precision in order to estimate accurately the distances between vehicles, while a reliable localization will ensure that updated information will always be available. In the following paragraphs we will discuss some of these applications and algorithms.

Vehicle Collision Warning Systems and are one of the most interesting applications of VANets for driver assistance. One part of these systems is Security Distance Warning, in which the driver is warned when a minimum distance to another vehicle is reached. It can also implement an emergency break when the distance between two vehicles or between a vehicle and an obstacle decreases too quickly. Another part of these systems is when a collision has already occurred and nearby vehicles need to be warned (warn messages) so they can avoid pile-up collisions. In these cases, multihop communication can be used to disseminate collision information. Since they provide a critical application for safe driving, these applications require robust, accurate, and reliable localization systems.

Another driver assistance application is Vision Enhancement, in which drivers are given a clear view of vehicles and obstacles in heavy fog conditions and can learn about the existence of vehicles hidden by obstacles, buildings, and by other vehicles.

Automatic Parking is an application through which a vehicle can park itself without the need for driver intervention. In order to be able to perform an automatic parking, a vehicle needs accurate distance estimators and/or a localization system with sub-meter precision.

2. TOPOLOGY ISSUES, THE TAXONOMY

The topology control is used by the wireless ad hoc and sensor networks to save energy reduce interference between nodes and extend lifetime of the network.

Topology control is a technique used n distributed computing to alter the underlying network (modeled as a graph) to reduce the cost of distributed algorithms f run over the new resulting graphs. It is a basic technique in distributed algorithms. For instance, a (minimum) spanning tree is used as a backbone to reduce the cost of broadcast from O(m) to O(n), where m and n are the number of edges and vertices in the graph, respectively.

Topology issues have been extensively studied in WSNs. Taxonomy of topological issues has been discussed in this paper that are named as follows:

- Topology Awareness problems: This is categorized into two parts, i.e. geographic routing and various sensor holes.
- Topology Control problems: In this section of problem there are several issues and that are mainly classified into two groups, they are:

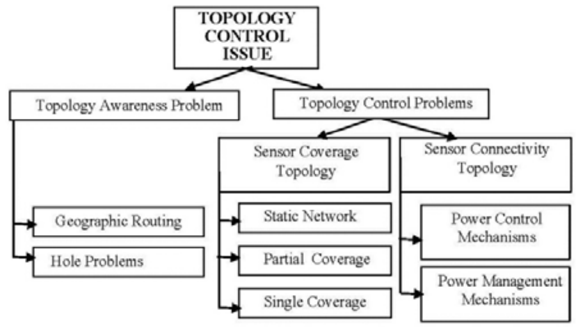

Figure-3. Taxonomy of topology control issues in WSNs.

Sensor coverage topology (includes static, mobile and hybrid network) and sensor connectivity topology (includes power control and power management mechanism). There are various problems that arise in sensor network as mentioned earlier. For that, several approaches have been taken into account to solve the above issues Viz. Greedy Perimeter Stateless Routing (GPSR) for MANETs, compass routing, BOUNDHOLE Algorithm, PEAS protocol, power control mechanism and power management mechanism, etc. Another form of technique is there to recover some topological issues that prevails in the sensor networks, is to implement Color based topology control Algorithm (CBTC Algorithm) [6]. There are two most important factors that should be deployed properly to maintain the performance of WSNs. The two main factors are: sensor node deployment and topology control. Both the factors have to be properly managed to guarantee the maximum lifetime of sensor nodes, minimize network delay and removal of sensor holes.

Topology issues have been extensively studied in WSNs. We divide the topology issues into two categories: Topology Awareness Problems and Topology Control Problems. Topology Awareness Problems include geographic routing problems and sensor holes problems. Geographic routing uses geographic and topological information of the network to achieve optimal routing schemes with high routing efficiency and low power consumption. Various sensor holes, such as Jamming holes, sink/black holes and worm holes, may form in a WSN and create network topology variations which trouble the upper layer applications. [7] For examples, intense communication may cause jamming holes which will fail to deliver message to exterior nodes. Sink/Black holes and worm holes are caused by nodes exhausted around sink node or pretended sinks or by malicious nodes. If sensor holes issues are not treated carefully, they

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will create costly routing table and exhaust the intermediate nodes rapidly.

Topology Control Problems can be further divided into two categories: Sensor Coverage Topology and Sensor Connectivity Topology. The coverage topology describes the topology of sensor coverage and is concerned about how to maximize a reliable sensing area while consuming less power. The connectivity topology on the other hand is more concern more about network connectivity and emphasizes the message retrieve and delivery in the network. Two kinds of mechanisms have been utilized to maintain an efficient sensor connectivity topology: Power Control Mechanisms and Power Management Mechanisms [8]. The former controls the radio power level to achieve optimized connectivity topology and the later maintains a good wake/sleep schedule.

3. TOPOLOGY AWARENESS PROBLEMS

3.1 Geographic routing

Geographic routing approach relies on greedy forwarding to route packets based on nodes' local information on the network topology. The protocol starts in greedy forwarding mode, and assumes the location information of sensor nodes can be obtained by supporting systems. GPSR recovers from local maximum position by using perimeter rouging mode and the right-hand rule. Compass Routing algorithm and FACE-1 algorithms that guarantees the destination is reached even when local minimum phenomenon occurs in greedy forwarding [9]. In contrast to GPSR, routing in FACE-2 is done through the perimeter of the Gabriel Graph (CG) formed at each node. It also modifies the FACE-1 so that the perimeter traversal follows the next edge whenever that edge crosses the line from the source to destination. Obviously, the downside of FACE-2 is that it consumes more energy in the perimeter nodes.

3.2 Holeproblems

For most of the geographic routing schemes, a routing hole consists of a region in the sensor network, where either node are not available or the available nodes cannot participate in the actual routing of the data due to various possible reasons. It provide a theoretical work on determining sensor holes in which so-called stuck node is defined and an algorithm called BOUNDHOLE [10] is proposed to find the holes utilizing the strong stuck nodes.

Topology maintenance protocol SASA, which claims to rapidly detect the structure variation during underground collapse by regulating the mesh sensor network deployment and formulating a collaborating mechanism based on the regular beacon strategy for sensors. The so-called edge nodes outline the sensor hole and report it to the sink. To the best of our knowledge, the SASA protocol is the first work which relates the topology variation to the actual geographical changes.

A jamming hole circumvents the ability of nodes in a specific area to communicate/sense so that a virtual hole emerges. Wood et al. propose a JAM [11] protocol to detect and map jammed regions in a sensor network. The detection part of the protocol applies heuristics based on available data, e.g. bit-error rates etc., to distinguish jamming from normal interference. The JAM protocol assumes that the location information and unique ID is known to each node.

Sink/Black holes and worm holes are gradually formed due to sensor node power exhausted and the possible denial of service attacks in the network. The sink hole is characterized by intense resource contention among neighboring nodes of the malicious node for the limited bandwidth and channel access. Worm hole is another kind of denial of service attack. It is formed when a malicious node causes nodes located in different parts of networks to believe that they are neighbors, which result in incorrect routing convergence.

Various routing protocols and energy conserving topology maintenance algorithms against sink holes. They showed that popular routing protocols like directed diffusion, rumor routing and multi-path variant of directed diffusion etc. are all vulnerable to sink holes. For geographical greedy forwarding algorithms it is more difficult to create sink holes because in this case a malicious node has to advertise different attractive locations to different neighbors in order to qualify as next hop. In the authorization solution, only authorized nodes can exchange routing information with each other. The solution is not scalable due to high computation and communication overhead. Also, public key cryptography is not feasible in sensor networks given the capacities and constraints of the sensor devices.

4. TOPOLOGY CONTROL PROBLEMS

4.1 Sensor coverage topology

We break this family of problems into small categories: Static Network, Mobile Network and Hybrid Network [12].

4.1.1 Static network

For a static sensor network, proposed approaches have different coverage objectives. We introduce these approaches separately.

4.1.2 Partial coverage

PEAS protocol consists of two algorithms: Probing Environment and Adaptive Sleeping [13]. In PEAS protocol, the node location information is not required as a pre-knowledge. Their scheme aims to partially cover the sensing area with each point eventually

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sensed within a finite delay bound. Their assumption is that the neighboring nodes have approximately synchronized clocks and know sensing ranges of each other.

4.1.3 Single coverage

Optimal Geographical Density Control (OGDC) protocol [14]. This protocol tries to minimize the overlap of sensing areas of all sensor nodes for cases when Rc ≥ 2Rs where Rc is the node communication range and Rs is the node sensing range. OGDC is a fully localized algorithm but the node location is needed as a pre-knowledge.

4.2 Sensor connectivity topology

4.2.1 Power control mechanisms

The goal of power control mechanisms is to dynamically change the nodes' transmitting range in order to maintain some property of the communication graph, while reducing the energy consumed by node transceivers because they are one of the primary sources of energy consumption in WSNs [15]. Power control mechanisms are fundamental to achieving a good network energy efficiency. Power control is studied in homogeneous and non-homogeneous scenarios which can be distinguished by examine if the nodes have the same transmitting range or not.

For homogeneous network, the CTR (Critical Transmitting Range) problem has been investigated in theoretical ways as well as practical viewpoints [16]. COMPOW that attempts to determine the minimum common transmitting range needed to ensure network connectivity. They show that setting the transmitting range to this value has the beneficial effects of maximizing network capacity, reducing the contention to access the wireless channel, and minimizing energy consumption. Non-homogeneous networks are more challenging because nodes are allowed to have different transmitting ranges. The problem of assigning a transmitting range to nodes in such a way that the resulting communication graph is strongly connected and the energy cost is minimum and it is called the Rang Assignment (RA) problem [17], and it was first studied. The computational complexity of RA has been analyzed. It is shown to be NP-hard in the case of 2D and 3D networks. However the optimal solution can be approximated within a factor of 2 using the range assignment generated. An important variant of RA has been recently studied is based on the concept of symmetry of the communication graph. Due to the high overhead needed to handle unidirectional links in routing protocols or MAC protocols which are naturally designed to work under the symmetric assumption, Symmetric Range Assignment (SRA) shows more practical significance. In the released WSRA problem, only marginal effect on the energy cost has been induced while the desired symmetry property has been kept. Two polynomial approximation algorithms for WSRA have been introduced.

A lot of power control approaches have been proposed which try to design simple and practical protocols that build and maintain a reasonably good topology.

4.2.2 Power management mechanisms

Power management is concerned of which set of nodes should be turned on/off and when, for the purpose of constructing energy saving topology to prolong the network lifetime. It can utilize information available from all the layers in the protocol stack. In GAF approach, nodes use location information to divide the field into fixed square grids. The size of each grid stays constant, regardless of node density. Nodes within a grid switch between sleeping and listening mode, with the guarantee that one node in each grid stays up so that a dynamic routing backbone is maintained to forward packets [18].

5. CONCLUSIONS AND FUTURE RESEARCH

In this paper, we present a comprehensive survey on topology issues in wireless sensor networks (WSN) for intelligent transportation systems (ITS). We provide our classifications of the problems and approaches. Under this frame, we list, review and compare some classical works in the field. At last, we highlight the challenges in this topic and point out some future research directions. In this survey paper, we reviewed two major topology issues in WSNs, namely topology awareness and topology control. Topology awareness problems take the approach of constructing applications or upper protocols to conform the underlying topology. Typical approaches applied in this category do not actively consider improving the topology itself for the specific applications. Topology control mechanisms focus more on constructing an energy-efficient and reliable network topology and normally do not touch the concrete applications above the topology. So the first major question we raise is how to relate the topology control mechanism to the upper topology aware applications more tightly in WSNs [19]. For topology control problems, sensor coverage topology and sensor connectivity topology have been separately discussed in most of the literatures. However, while the sensing coverage topology represents the network sensing ability, the connectivity topology should as well maintained as a necessity for the successful information delivery, including queries, sensing data and control messages. How to construct an optimized coverage topology while maintaining efficient and low cost connectivity is not well understood and deserves further studies.

Power control and power management are two different types of topology controlling methods. The combination of the two has not yet well studied. We believe by integrating power control and power management, it is possible to provide noticeable improvements on network topology and efficiencies of energy usage. This is another interesting research topic for the researchers in the field.

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