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COMPARATIVE ANALYSIS OF TOPOLOGY CONTROL ALGORITHMS TO ENHANCE NETWORK LIFETIME

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ABSTRACT

Topology issues have received more and more attentions in Wireless Sensor Networks . WSN applications are normally optimized by the given underlying network topology. Topology control is an effective method to improve the energy efficiency of wireless sensor networks. Due to the severe resource limitations of the sensor nodes (e.g., small battery, limited computation capabilities, inexpensive transceiver etc.), Lifetime extension is one of the most critical research issues in the area of wireless sensor networks. One of the key approaches for prolonging the sensor network operable lifetime is to deploy an effective topology control protocol. In this survey paper, we provide a full view of the studies in the area of topology control in Wireless sensor network. By summarizing previous achievements and analyzing existing issues, we also point out challenges and research directions for future work.

Keywords: wireless sensor network, topology control, lifetime extension, energy efficiency.

1. INTRODUCTION

In case of sensor networks several hundreds to thousands of nodes are deployed throughout the field of interest. The distance between the nodes is either known or random. The densely deployed sensor nodes require careful handling of topology maintenance. There are three phases: pre-deployment phase, post-deployment phase and redeployment phase.

Due to advancement in technologies and reduction in cost of technologies and reduction in size, sensors are becoming involved in almost every field of life. Agriculture is one of such domain where sensors and their networks are successfully used to get numerous benefits. Agriculture has played a key role in the development of human civilization. Due to the increased demand of food, people are trying to put extra efforts and special techniques to multiply the food production. Use of different technologies towards agriculture is one of such efforts. Information technology is now being heavily used in this area.

Wireless sensor networks (WSN) in agriculture have become one of the most popular technologies for agriculture monitoring system[22][23][25]. WSNs can be widely used such as agriculture, Industry, Medicine, Horticulture and Military. From these various fields agriculture application is considered one of the most promising services for WSN realization to enhance the food crop production. Terminologies for Agriculture based on WSN now in use like precision agriculture(PA), Smart agriculture, Precision farming, Global positioning, Variable rate technology (VRT) farming, Information intensive Agriculture, Site specific crop management, but the underlying principal in all of them is same[21].

For deployment of WSN systems for monitoring purpose in agriculture environments, a number of open problem remain. Some of the examples of such problems are,

a) The agriculture monitoring system with various sensors should record and store measured information. It is used to establish an agriculture database system which may provide Analysis of crop growth and harvesting prediction, by using analyzed patterns of changing conditions in forms[18][20].

b) Crops are vulnerable to weather conditions such as temperature, humidity, intensity of illumination. In indoor environments, the occurrence of fire is one of the most fatal agriculture disasters.

c) Due to increased industrial developments air pollutions are prevalent worldwide. The agriculture monitoring system should not only detect various air pollutions but also report to farmer.

1.1. Issues of wireless sensor network

Recent emergences of affordable, portable wireless communication and computation devices and associated advances in the communication infrastructure have resulted in the rapid growth of wireless networks. *Ad hoc networks* are the ultimate frontier in wireless communication. Ad hoc networks are expected to revolutionize wireless communications in the next few years: by complementing more traditional network paradigms (Internet, cellular networks, and satellite communications), they can be considered as the technological counterpart of the concept of ubiquitous computing.

Wireless sensor networks (WSNs) are a particular type of ad hoc network, in which the nodes are 'smart sensors'. Sensor networks are expected to bring a breakthrough in the way natural phenomena are observed: the accuracy of the observation will be considerably improved, leading to a better understanding and forecasting of such phenomena[27][33]. The expected benefits to the community will be considerable. Although the technology for ad hoc and sensor networks is relatively mature, the applications are almost completely lacking. This is in part due to the fact that some of the problems related to ad hoc/sensor networking are still unsolved. In case of sensor networks also, many challenges are still to

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be faced before they can be deployed on a large scale. The main challenge related to WSN implementation is Topology Control. WSN technology poses many issues that need to be handled for long term viability of developed systems. Issues like energy consumption for autonomous operation of sensor nodes, development issues including communication, protocols and deployment. Issues in WSN have been outlined in existing literature. Some of these issues are Energy consumption, Data processing and consumption, Sensor placement and Event detection[30][31].

1.2. Topology control

Topology control is an effective method to improve the energy efficiency of Wireless sensor networks (WSNs). It is beneficial but very complex process. If it is not performed carefully may produce undesired result. Following considerations are important while designing topology control mechanism: Distributed Algorithm., Local information., Need of local information., Connectivity, Coverage., Small node quantity and Simplicity. In traditional model, network model is based on the assumption that a pair of nodes is either “connected” or “disconnected”. When all nodes are connected to the network, network is said to have full connectivity. This approach is called as connectivity based topology control. Figure-1 shows taxonomy of topology control[28][30].

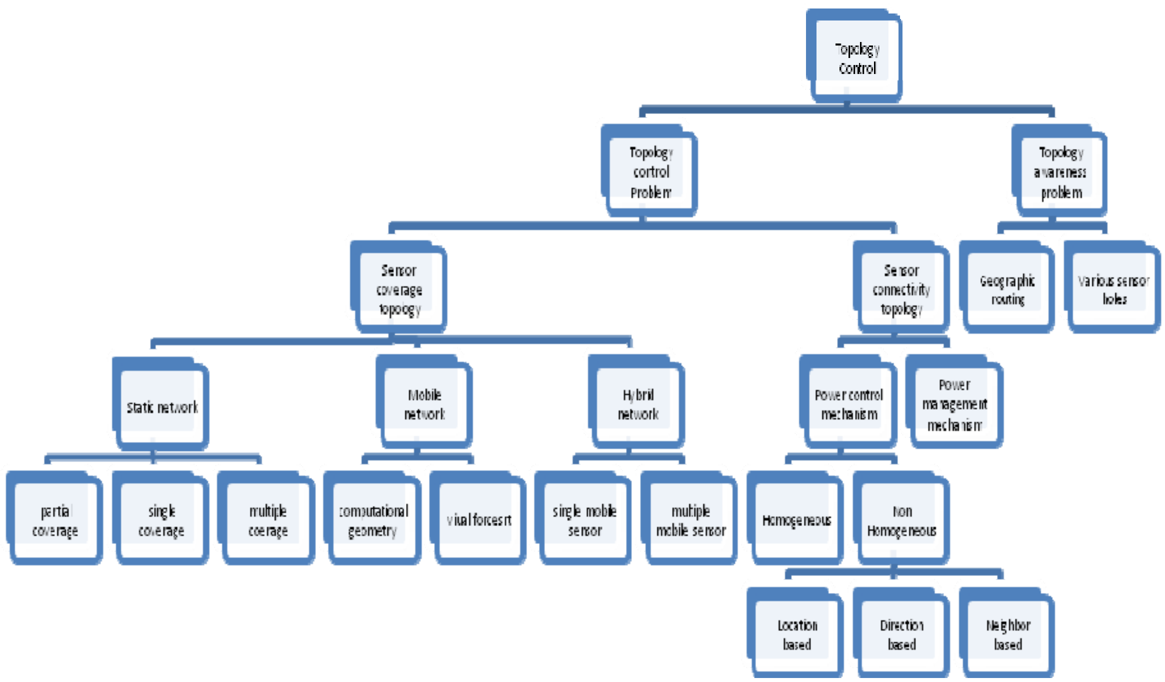

Figure-1. Taxonomy of topology control algorithm.

The topology of a wireless sensor network refers to the network layout or network shape, the "set of communication links between node pairs used explicitly or implicitly by a routing mechanism" Raman than and Rosales-Hain, 2000. The topology of a network is the basis for its performance with nearly all the important properties such as routing efficiency, capacity and connectivity, relies on it. Why do we need to control the topology? Simply because without proper topology control algorithm in place, a randomly connected wireless sensor network may suffer from short network lifetime, poor network utilization, high interference, considerable reduction in the capacity, high end-to-end packet delays, and decrease in the robustness to frequent node failures. For instance, if the topology is too sparse, there may be a danger of network partitioning and high end-to-end delays. On the other hand, if the topology is too dense, the limited spatial reuse reduces network capacity. Networks that do not employ topology control are likely to be in one of these scenarios for a significant fraction of their operational time, resulting in degraded performance or even disrupted connectivity. Figure-2 shows how a topology control can be employed to trim off inefficient links in a wireless sensor network.

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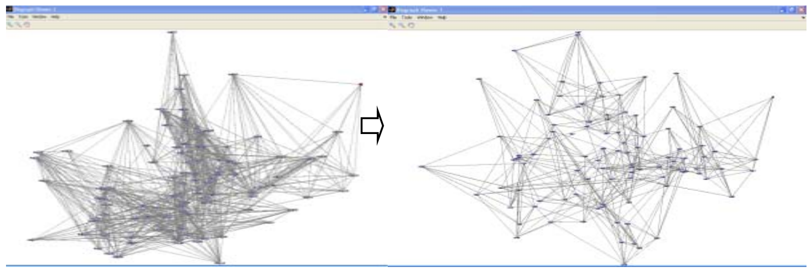

Figure-2. Before topology control After topology control

Network topology depends on many uncontrolled factors such as the node mobility, node failure, weather, interference, and noise, as well as some controlled parameters such as transmission power, use of directional antennas (Srivastava *et al.*, 2003) and the node's duty cycle (on/off). In this section we address the problem of controlling the topology of the wireless sensor networks by (a) controlling a node's transmit power through power-control algorithms or (b) manipulating a node's state through multi-state based algorithms. The effect of even a simple topology control algorithm on throughput and network lifetime is significant. The subject of topology control in regards to wireless ad-hoc networks has been widely discussed. Some topology control algorithms have been specifically proposed for sensor networks. Such topology control algorithms deal with limitation of wireless sensor networks, such as power usage and network capacity.

In real time application environments, this connectivity based model is not practical. This is due to transitional region phenomenon. Beyond the connected region there is a transitional region that allows wireless link to be intermittently connected. In WSN communication consumes a significant amount of energy. As the distance of communication increases, the probability of getting a line-of-sight (LOS) link decreases [1] in which case the path loss index can no longer be 2 but between 2 and 4. By reducing the distance of communication to a shorter length. It is possible to keep a LOS link which reduces the transmission cost.

A topology Control protocol is necessary to set an upper and lower bound on the number of links that can be active in the network. It ensures that network remains connected and its lifetime is optimized. In wired networks, the way the network elements are physically interconnected directly influences the network topology. A topology control protocol deals with all these dynamics and ensures that the network is connected with energy efficient links. The main challenge is to develop a topology control strategy that is simple, scalable and less resource intensive, it should function based on local information only. In most cases additional knowledge such as the placement and relative position of a node to the sink node can be obtained from layout information. We propose a localized algorithm that enables node to autonomously create and maintain energy efficient links. The protocol defines proximity and eligibility metrics to ensure network connectivity and to optimize lifetime.

1.3. Topology control problems

1.3.1. Sensor coverage topology

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

1.3.1.1. Static network

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

a. Partial coverage

The Ye *et al*. propose PEAS, which extends WSN system functioning time by keeping only a necessary set of sensors working in case the node deployment density is much higher than necessary. PEA's protocol consists of two algorithms: Probing Environment and Adaptive Sleeping. In PEAS protocol, the node location information is not required as a pre-knowledge. Cao *et al*. develop a near-optimal deterministically rotating sensory coverage for WSN surveillance system. Their scheme aims to partially cover the sensing area with each point eventually sensed within a finite delay bound. Their assumption is that the neighboring nodes have approximately synchronized clocks and know sensing ranges of each other.

b. Single coverage

For single coverage requirement, Zhang *et al* have proposed the Optimal Geographical Density Control (OGDC) protocol. 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.

c. Multiple coverage

Wang *et al*. present the Coverage Configuration Protocol (CCP) that cans flexibility in configuring sensor network with different degrees of coverage. The CCP protocol needs node location information as assistance.

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Huang *et al*. Propose polynomial-time algorithms to verify whether every point in the target area is covered by at least the required number of nodes. The authors suggest a central controller entity that can collect the details of sufficiently covered segments and dispatch new nodes to supplement. However, this centralized approach lacks scalability Yan *et al*. propose a distributed density control algorithm based on time synchronization among the neighbors. A node can decide its on-duty time such that the whole grid still gets the required degree of coverage.

1.3.1.2. Mobile network

Wang *et al*. study the deployment schemes for movable sensors. Given an area to be monitored, the proposed distributed self-deployment protocols first discover the existence of coverage holes in the target area then calculate the target positions and move sensors to diminish the coverage holes. Voronoi diagrams [2, 3] are used to discover the coverage holes and three movement-assisted sensor deployment protocols VEC, VOR and Minimax are designed. Howard *et al*. and Heo *et al*. Study the sensor network in the viewpoint of virtual forces. In this approach nodes only use their sensed information to make moving decisions. It is a cost effective and no communication among the nodes or localization information is needed. For the DSS (Distributed Self-Spreading) sensors are randomly deployed initially. They start moving based on partial forces exerted by the neighbors. The forces exerted on each node by its neighbors depend on the local density of deployment and on the distance between the node and the neighbor. Table-1 describes the different protocols and their categorization with respect to network types.

Table-1. Comparison of static/ mobile protocol.

Protocols	Mobile/ static	Category	Location info	Distributed	Major Characteristics
Span[33]	Static	Asyn.	No	Yes	Routing backbone
GAF[24]	Mobile	Asyn.	Yes	Yes	Grid-based division
Power saving protocol[8]	Mobile	Asyn.	No	Yes	Beacon and MTIM windows
STEM[10][15]	Static	Asyn.	No	Yes	State switching
Asynwakeup protocol[4]	Static	Asyn.	No	No	Symmetric block design
S-MAC[5]	Static	Syn.	No	Yes	Fixed duty cycling
T-MAC[12]	Static	Syn.	No	Yes	Adjusted duty cycling
Wise-MAC[34][8]	Static	Asyn.	No	Yes	Low power listening
X-MAC[4]	Static	Asyn.	No	Yes	Abbreviated preamble sampling
SCP-MAC[4]	Static	Hybrid	No	Yes	Strobed preamble sampling
C-MAC[4]	Static	Asyn.	No	Yes	RTS/CTS based preamble sampling
RI-MAC[4][13]	Static	Asyn.	No	Yes	Receiver initiated

1.3.1.3. Hybrid network

The coverage scenario with only some of the sensors are capable of moving has been under active research, especially in the field of robotics for exploration purpose. The movement capable sensors can help in deployment and network repair by moving to appropriate locations within the field to achieve desired level of coverage. Batalin *et al.* Suggest a combined solution for the exploration and coverage of a given target area. The coverage problem is solved with the help of a constantly moving robot in a given target area. The algorithm does not consider the communications between the deployed nodes. All decisions are made by the robot by directly communicating with a neighbor sensor node. Wang *et al*. [4] address the single coverage problem by moving the available mobile sensors in a hybrid network to heal coverage holes. Table-2 describes Protocols with respect to single or multiple coverage.

Sensor networks are composed of nodes with sensing capabilities which perform distributed sensing task. When dealing with a large number of nodes, sensors have to be deployed randomly and their final positions cannot be engineered in advance. From the random positioning of nodes two fundamental problems arises: i) Maintaining a connected topology for communication purposes (Topology Control) ii) Identifying the geographic position of nodes for sensing purposes (localization). Some of the issues to be considered in the design stage are Energy Conservation, Limited bandwidth, Unstructured and time varying network topology, low quality communication, data processing and scalability. With the awareness of underlying network topology most efficient routing could be achieved. Energy can be saved if network topology can be maintained in optimum manner.

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Table-2. Protocols with single and multiple coverage.

Protocols	Category	Approach	Major assumptions	Key characteristics
OGDC	Static	Single coverage	Location information, Uniform sensing disk	Residual energy consideration
Sponcered area	Static	Single coverage	Location information	Sector based coverage calculations
Extended-sponcered area	Static	Single coverage	Location information, time synchronization	Uniform disk sensing model
VD	Static	Multiple coverage	Binary sensing, disk coverage	Uncertainty sensor placement, k-coverage guarantee
uScan	Static	Two level	Location information time synchronization	Unifies coverage architecture
VEC, VOR, minmax	Mobile	Computational geometry	Location information	Localized, scalable, distributed
Co-Fi	Mobile	Computational geometry	Location information, nodes predict their death	Single coverage based, Residual energy consideration
Potential fields	Mobile	Virtual forces	Range, bearing	Scalable, distributed, no local communication req.
DSS	Mobile	Virtual forces	Location information	Scalable, distributed, residual energy based
Single robot	Hybrid	Single mobile sensor	Location information	Distributed, no multi-hop communications
Bidding protocol	Hybrid	Multiple mobile sensor	Location information	Voronoi diagram is used for the single coverage requirement

Table-3. Comparison with respect to assumption and characteristics.

S. No.	Assumptions	Protocol	Characteristics
1	Power dynamic partial adjustment	PEAS	Distributed sleeping schedule.
2	Location info.	Sponsored area	Sector based coverage calculations
		CCP	Configurable degree of coverage
		k-UC, k-NC [5]	Non-unit disk model supported
		DSS [6]	Scalable, distributed. residual energy based.
		Single robot [7]	Distributed. No multi-hop communications
		Bidding protocol [4]	Voronoi diagram is used for single coverage requirement
		VEC, VOR, minmax	Localized, scalable, distributed.
		INF [8]	Active NAKs and source initiated repair
		Active message relay [9]	By node movement to reach disconnected neighbors
3	Range and bearing	Potential fields [10]	Scalable, distributed. No local communication required
4	Location info, nodes predict its death	Co-Fi [11]	Single coverage based. Residual energy considerations.
5	Location info, synchronized clock	Differentiated	Grid based differentiated degree of coverage
6	Location info, uniform sensing disk		Residual energy consideration
7	Location info and the whole planar graph (GG)	Compass routing [12] FACE II [1] GOAFR+ [13]	Face routing on planar graph to avoid routing holes
		GPSR [14]	Right-hand rule in perimeter mode to round the voids
8	Location info and learned and estimated cost values	GEAR	Learned and estimated cost for energy efficient geographical routing, and limited flooding in region

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2. RELATED WORK

In [2] concept of distributed topology control algorithm to conserve energy is introduced. In this paper localized distributed Topology control algorithm is presented. It calculates optimal transmission power to active network connectivity. It reduces node transmission power to cover nearest neighbor. A node uses only the locally available information to determine nodes.

Majority of work has been done on fault tolerant topology control algorithm to minimize the total power consumption. It provides k-vertex connectivity between two vertices. Michaela Cardei *et al* [7] propose new architecture to achieve minimum energy consumption by using k-approximation, centralized greedy, distributed and localized algorithm. It provides reliable data gathering infrastructure from sensors to super node[43][22].

Andrew Ka-Ho Leung and Yu Kwong Kwok [15] have proposed a new localized Application driven Topology Control Protocol. This scheme is designed for a wireless P2P file sharing network. Their proposed scheme is based on enhancing the lifetime and effectiveness of file sharing among peers. Authors tried to achieve an efficient connectivity among mobile devices in order to better serve the file sharing application. Their designed protocol consists of two component 1) Adjancy set construction (ASC) 2) Community base Asynchronous wakeup (CAW). Waltenegu Dargie *et al* (2010) proposed topology Control protocol [1]. The developed protocol enables nodes to exhaust their energy fairly. This paper proposes algorithm-based on eligibility and efficiency of nodes. In this paper, authors presented a shortest path and energy-efficient topology control algorithm[45][4][26][29]. The algorithm tries to preserve shortest path connecting itself to nearby nodes and the minimum-energy paths.

Research work carried out by [16] authors examines the price of ignorance in topology control in cognitive network with power and spectral efficiency objective. They proposed distributed algorithm that, if radio posses global knowledge, minimize both the maximum transmit power and spectral footprint of the network. They showed that while local knowledge has little effect on the maximum transmission power used by the network, it has the significant effect on the spectral performance. They have presented an approach for achieving end to end objective through learning and reasoning. For dynamic networks, as radios join the network, more knowledge provides better spectral performance. When radio leaves the network, some ignorance in the network results into better performance[44].

Yunnai Liu *et al* [17] presented a paper on "Connectivity based Topology Control." Authors proposed that there are many intermittently connected wireless links called lossy links. Authors proposed CONREAP algorithm by exploring reliability theory. Experimental results showed that CONREAP is more appropriate for low density requirements. Algorithm can improve energy efficiency up to 6 times.

Table 4. Comparison with respect to key characteristics.

Category	Type	Major assumptions	Key characteristics
Barrier[23]	k-barrier testing, barrier deployment	Deterministic deployment	NP-Hard proof, critical conditions for weak coverage
Barrier[9]	Barrier deployment	High degree of connectivity	Strong coverage, distributed algorithm
Barrier[11]	barrier deployment	Location Info.	Strong coverage, distributed algorithm, near optimal performance
Barrier[7]	barrier deployment	Poisson point process	Irregular shape barrier, strong coverage, critical conditions
Barrier[12]	barrier deployment	Location Info.	Line based barrier
Sweep[28]	Theoretical analysis, protocol design	Fixed POI positions	Theoretical foundation, 2+ ε approximated algorithm
Sweep[33]	Protocol design	Direction of communication node is known	Dynamic POI positions, information potentials

Antonio-Javier Garcia-Sanchez [18] proposed an integrated WSN based system for crop monitoring, video surveillance and process cultivation control. This network implies an innovative redeployment of precision agriculture using IEEE 802.15.4 cost effective technology. Their approach has been developed to conduct all these functions not only in a single crop but also in deployments considering scattered crops separated several kilometers from the farmer's cooperative premises. The complete system satisfies all these requirements, providing an efficient and coordinated communication infrastructure among the different sensing node placed in crops and end user.

Tapiwa M. Chiwewe proposed [19] three phased topology control algorithm which executes distributive per node. A node uses only local available information to determine the node that should be its logical neighbor at any given time. They developed locally distributed algorithm in a mobile environment. In this work the problem topology control in a hybrid WMN of

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heterogeneous wireless devices with varying maximum transmission ranges is considered.

Hiroshi Nishiyama *et al* [20] proposed a dynamic method of effectively employing k-edge connected topology control algorithm in MANETs. This method automatically determines the appropriate value of *k* for each local graph based on local information. It ensures the required connectivity ratio of the whole network. The results show that dynamic method can enhance the practicality and scalability of existing k-edge connected topology control algorithm while guaranteeing the network connectivity.

Azrina Abd Aziz *et al* [8] focused on energy efficiency issues and presented study of topology control techniques for extending the lifetime of battery powered WSNs. Authors considered that energy consumption and network lifetime are two commonly used evaluation metrics for measuring the impact of topology control algorithm on energy efficiency. They have identified number of open research issues for achieving energy efficiency through topology control.

Topology control has been widely studied. CBTB (Cone based distributed topology control) is among the first algorithm that adjusts the transmission power to save energy consumption. In this algorithm it is ensured that in every cone of degree α around u can reach with power *Pu*. The author proved that if $\alpha<5/6\pi$, th e connectivity is preserved. Frank and Tardus study the k - connectivity from the root to any other node, with the objective of minimizing the total weight of the edges. They propose a polynomial time optimal solution using a maximum cost sub modular flow problem.

Wattenhofer propose a topology control protocol to dynamically adjust transmission power based on local decisions. A node increases its transmission power until it finds a neighbor node in every direction. But the question how a node trims off inefficient links in case it discovers several neighbors is not addressed. The work in address the fault -tolerant topology control with the objective of minimizing the maximum power consumption. Raman than and Rosales-Hain propose a centralized greedy algorithm for assuring biconnectivity (k=2) that iteratively merges two disconnected components until only one remains. Relative neighborhood graph(RNG) is also used to reduce the number of links between a node and and its neighbors. An edge belongs to the RNG only if it is not the longest leg of any triangle it may form in the original graph.

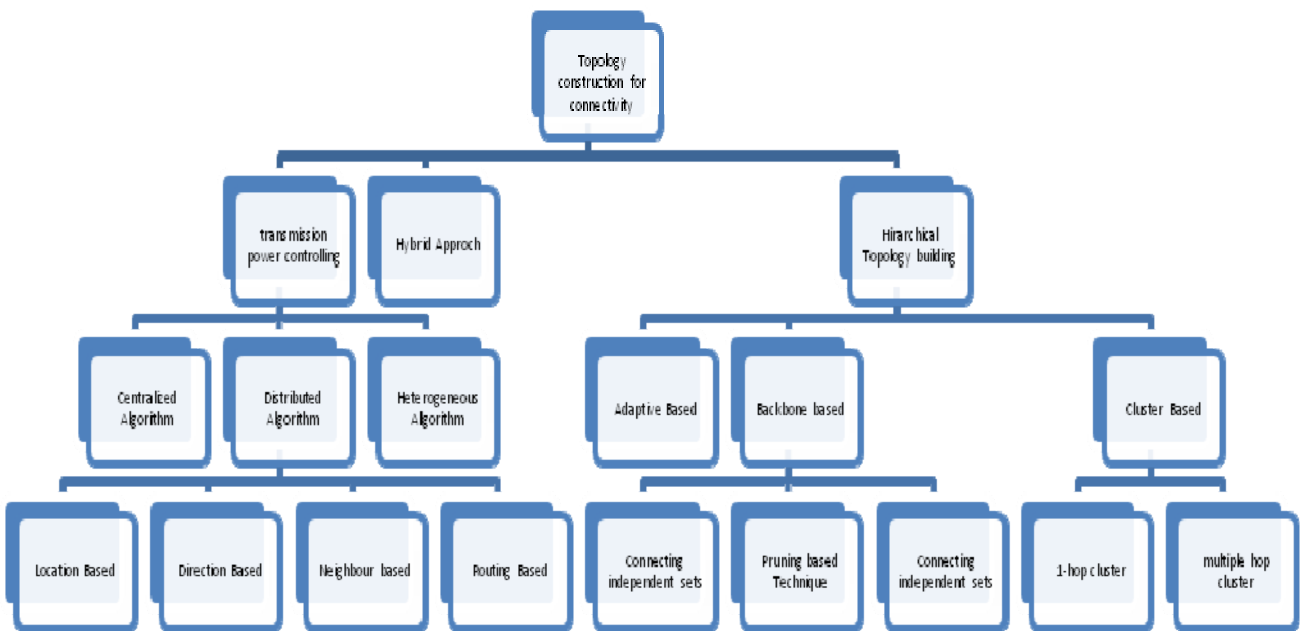

Figure-3. Taxonomy for Topology Construction Algorithm

Li et al proposed a minimum spanning tree based algorithm for topology control. LMST is a localized algorithm to construct MST based topology in adhoc networks by using only information of nodes which are one hop away. Every node knows its position by GPS and has its ID for identification. The idea of LMST is simple. Each node calculates MST independently from the information of one hop nodes and only keeps one-hop on tree nodes as neighbors. The node degree of any node is bounded by 6. This can help reduce MAC level contention and interference. The resulting topology can be converted into the one with only bidirectional links by removing all unidirectional links. The topology of resulting LMST might be split by single failure. Topology in an adhoc network should have some redundancy because of its unsure links. In recent years some approaches have been proposed. In the authors assumed that nodes may act in their self interest. They modeled interactions among nodes as a game and analyzed the problem as a non Cooperative game. In [1][16] authors proposed an algorithm to

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optimize the traditional topology control scheme. This algorithm starts from symmetric connected topology which assumes to be the output of topology control. This can be applicable to many topology control schemes. ASCENT turns the nodes on/off depending on assessment of operating conditions (neighbor threshold and packet loss threshold). it uses the redundancy of nodes over time to extend network lifetime , each node ases its connectivity and adapts its participation in the multihop network topology based on the measured operating region.

A node signals when it detects high data loss, requesting additional nodes in the region to join the network to forward messages. A node may reduce its duty cycle if it detects high data losses. Due to collision ASCENT has the potential for significant reduction of packet loss rate and increases in energy savings as well as its mechanism are responsive and stable under systematically consumes energy equally or fairly. ASCENT may employ a load balance policy that allows nodes to switch state from time to time between active and non active in order to ensure all nodes share the task of providing global connectivity equally and distribute the energy load. It has too many parameters to be configured which make it difficult to be optimized.

3. COMPARISON OF TOPOLOGY CONTROL ALGORITHMS

In this section comparison of different topology control algorithm is given.

3.1. POLY: A reliable and energy efficient topology control protocol for wireless sensor networks

In mission critical application where packet loss is not acceptable. Generally it is assumed that packet, when nodes in WSN are connected to their neighbor, there is a possibility of packet loss, and therefore reliability should be achieved while improving energy efficiency. Topology construction and maintenance are two phases of topology control. Topological property is established in the construction phase. Connectivity should be maintained in the construction phase. Connectivity should be maintained in the construction phase. Second phase is the topology maintenance phase In

CDS based Topology control scheme, some nodes are part of virtual backbone Non CDS node conserve energy by turning off radios. To achieve reliability and energy efficiency CDS size is an important parameter. For small CDS network traffic is handled by very few nodes, resulting into draining the battery. This is disadvantages of CDS. The advantage of this system is more nodes can go to sleep mode. “Saving energy compromises reliability” Poly is semi distributed graph theoretic topology control protocol for WSN. It finds the number of polygon present in the network. By modeling network as connected graph. To achieve energy efficiency, the protocol forms a CDS like polyphonic network which in turn provide reliability in the case of random link failure. It adapts to topological changes in the remaining energy of nodes.

Table-5. Comparison of power adjustment, power mode , clustering and hybrid approach.

Category	**Algorithm**	**Advantage** (s)	**Disadvantage** (s)
Power Adjustment	MECN (Minimum Energy Communication Network)	Strong connectivity	Needs location information (GPS) system to build topology
	SMECN (Small Minimum Energy Communication Network)	Strong connectivity. More power and time efficient than MECN	Needs location information (GPS) to build topologies.
	COMPOW (Common Power level)	Practical-based topology control. Built on a wireless testbed	High message overhead for computing multiple power levels
Power Mode	GAF (Geographical Adaptive Fidelity)	Low communication overhead	Relies on location information system to compute allocate nodes to the grid.
	STEM(Sparse Topology and Energy Management)	Energy efficient for event-triggered Applications	Trade-off energy savings with setup latency
	ASCENT (Adaptive Self-Configuring Sensor Network*))* *Topologies*	Self-reconfigurable and adaptive to react to applications’ dynamic events	Possibly fast energy depletion among active nodes due to uneven load distribution
Clustering	PACDS (Power Aware Connected Dominating Set)	Simple and quick to calculate the connected dominating set	Not suitable for high mobility
	ECDS (Energy Efficient Distributed Connecting Dominating) Sets)	Node’s energy residual considered in the construction of connected dominating set	High message overhead
Hybrid	SPAN	Location service-free and exploits advantage of power saving 802.11 for routing	Nodes have to periodically wakeup and listen for traffic advertisements
	CLUSTERPOW (Cluster Power)	Easy maintenance of clusters and possible implementation on a wireless card	Significant message overhead for computing multiple power levels
	LEACH (Low-Energy Adaptive Clustering Hierarchy*)*	Offers a variety energy efficient Mechanisms	Complicated tasks performed by Cluster heads and not scalable

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3.1.1. Poly protocol working

The resulting topology provides a desired level of packet delivery and energy consumption is less than CDS. It has low message overhead. Among a set of nodes , poly protocol forms a closed path. It provides reliable and energy efficient topology because it allows nodes to use an alternative in case of random link failure. Position or orientation information is not considered by this protocol. For energy saving dormant nodes are entered into sleep mode. Three types of messages are used by Poly at the time of the polygon formation process: Hello, Create topology, Finish discovery. Parent id of the sender is contained in hello message. To announce the end of topology discovery finish discovery message uses a create topology message containing the IDS of the active node set is propagated in the network[35][36].

3.1.2. Topology construction protocol

The neighbor discovery process is initiated by sink node and CDS is created in this first phase of topology construction. In the second phase sink node received neighbor list. Discovery of polygons in the graph is done in the last phase. Polygon nodes are informed that they are part of the active node set. Poly algorithm selected a random node as an initiator node. If more than one node initiates a process, the performance will be given to node having largest ID. The hello of node A is received by B, F and H. These are the uncovered nodes[37][38].

3.1.3. Complexity analysis of poly

Complexity of the CDS discovery process is same for A3, EECDS and CDS rule protocol but POLY have lower CDS discovery message complexity because it uses wireless broadcast for parent discovery. After CDS discovery A3, EECDS and CDS Rule protocols do not have any additional overhead, Poly introduces additional complexity. To reduce this additional complexity. Author discovers a subset of the cycle, they haven't considered all the cycles in the network. Therefore sink node processes a reduced subset of a message's path and few cycles. . Author also utilized cycle merging smaller cycles are combined to form larger cycles. The additional complexity of poly protocol represents a tradeoff between reliability and energy efficiency. The size of the polygon in the protocol is a critical parameter for evaluation of the algorithmic metrics is:

Message overhead: It is defined as total no of packets sent-received generated in the whole network during an experiment. Message overhead is directly proportional to energy consumption. Lower the message overhead, lower energy will be consumed. Every protocol designed in WSN is always trying to minimize this overhead[41][42].

Energy overhead: it is defined as the fraction of network energy expended during construction of topology. In case of topology maintenance this metric calculates overhead during reconstruction of topology under dynamic condition.

Residual energy: it is defined ratio of energy in the active set of nodes to the total network energy at the end of an experiment. Residual energy is a measure of network lifetime. As residual energy falls below a certain threshold value the probability of network partitioning increases.

Connectivity: connectivity refers to the number of nodes which are disconnected from the sink node after the activation of topology maintenance technique. This parameter measures the effectiveness of the topology construction protocol. If the connectivity value equals to zero, protocol is the best one. Higher value of connectivity shows that the protocol is unable to provide the backbone.
The message and energy overhead of EECDS, CDS-rule and A3 protocol compared with POLY. Among these three A3 has a low message and energy overhead due to its three way handshake protocol. Poly protocol has low energy overhead and greater message overhead than A3.A3 uses signal strength as selection metric for node selection in CDS. In grid topologies nodes are placed at equal distances which results in more energy overhead. For a selection of node in proportion to the size of the network broadcast mechanism is used by poly. It results in better residual energy as compared to other protocol[39][42].

An increase in the node degree leads to an increase in the number of messages exchanged. Poly has been providing better residual energy because.

a) The active node set is proportional to network size.
b) Rebroadcast mechanism is used by poly, it consumes battery of node at an equal rate.

3.2. Edge betweenness centrality: A novel algorithm for QoS-based topology control over wireless sensor networks

EBC is based on SNA (Social network analysis) and measure the importance of each node in the network. QoS is achieved by evaluating relationship between entities of network (i.e. edges) and identifying different roles among them (e.g. brokers, outliers) to control information flow, message delivery, latency and energy dissipation among them. This algorithm is applicable in homogeneous network and proposes different line of research: Topology control in terms of QoS requirement. Given a set of nodes performing specific task e.g. sink node in environmental sensor networks. Topology control algorithm is to select from the target network appropriate logical neighbors' of the former nodes, namely a subset of physical neighbors' of former node that can be used to perform application specific procedure, without the need of involving rest of physical neighbors' during execution of these procedures. QoS based topology control algorithm selects suitable set of logical neighbors' such that input QoS requirements can be satisfied. EBC is bidirectional,

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weighted topology control algorithm. It is compared with GG, RNG and closeness centrally.

Steps used to compute the edge betweenness centrality index are

a) Compute shortest paths through the network by means of Dijkstras (Dijkstra , 1959) algorithm
b) For each edge , compute the edge betweenness centrality index like in Newman(2004), but instead of unweighted edges use the average energy of two connecting nodes as edge weight (Cuzzocrea *et al.* , 2012)

3.2.1. Analysis of EBC

EBC try to minimize the energy consumption of nodes by transmitting data to a subset of nodes physical neighbors. EBC compared with GG, RNG and CC in terms of energy consumption and logical neighbors. EBC finds least no of logical neighbor. For 1000 nodes, GG found 3742 logical neighbor, whereas EBC found 1513 logical neighbors. Performance of algorithm is same for sparse as well as dense network.GG and RNG are unable to efficiently cope up with the increase of number of sensor placed in the terrain. As logical neighbors are less in EBC, energy consumption is less. Other performance evaluation metrics are:

Logical neighbors: EBC selects logical neighbors of actual node based on : 1. For each node , two hop node neighborhood must cover by logical neighbors. 2. One hop neighbor with high scoring betweenness index are selected[42][34].

Energy consumption: it energy should be minimum.

Hit-ratio: it is considered to be the ratio of answers received over the total number of queries that were produced.EBC performs best with lowest hit ratio of 83% and highest of 94%[36][38].

Latency: it is considered to be the time passed between issuing a query and receiving an answer to it.

EBC aim at providing high QoS by maximizing network lifetime and ensuring message delivery. And it is superior over GG, RNG and CC in terms of logical neighbors found, hit ratio, latency and energy consumption.

3.3. A distributed topology control technique for low interference and energy efficiency in WSN

The major challenge for WSN in agriculture is that, sensor nodes are resource constraints. Topology of network is dynamic and nodes are prone to failure, as it is deployed in the harsh environment. This algorithm is used to enhance energy efficiency and to reduce radio interference. Decision about transmission power is taken by node locally. Cumulative decision by each node is considered for global connectivity. SBYaoGG algorithm ensures that network links are symmetric and energy efficient. As compared to RNG, GG, Yao graph improves efficiency and effectiveness. This algorithm is a mixture of the Gabriel graph and the Yao graph algorithm, with the use of smart region boundaries. The algorithms referred to as the Smart Boundary Yao Gabriel Graph (SBYaoGG). The topology is generated by first computing the Gabriel graph from the Unit Disk Graph (UDG) at maximum transmitter power and then computing the Yao graph on the reduced topology to produce the final topology. The algorithms is compared according to distance stretch factor, logical node degree, physical node degree, and edge length.

Distance stretch factor: The maximum distance stretch Factor shows energy efficiency in terms of end to end multihop communication from source to sink and not from hop-to-hop, which is represented by the average edge length.

Logical node degree: The average logical node degree shoes the number of neighbors a node will have and gives an indication of how big its routing table will be. The average logical node degree of the SBYaoGG compared with the Delaunay graph, the Gabriel graph, the RNG, and the MST.

Physical node degree: The average physical node degree show the number of nodes affected by transmissions from a single node and is a measure of interference and spatial reuse.

Edge length: The average edge length shows energy efficiency in terms of hop to hop communication and is an indicator of individual node lifetime. all of the requirements for the topology control technique were met. This contributed to meeting the objectives of the final graph in that it is energy efficient and has low interference. A low physical node degree necessary for minimal interference and a low-power stretch factor necessary for high energy efficiency are two opposing goals, as has been noted.

3.4. RNG: Relative neighborhood graph.

The Relative Neighbor Graph (RNG) eliminates the longest edge from every triangle formed by two of its neighbors and itself. Formally, the RNG $G = (V, E)$ *of* a graph $G = (V, E)$ is defined as: where $d(u, v)$ is the Euclidean distance between two nodes. The RNG can be easily determined using a local algorithm with message complexity $O(n)$ and computational complexity $O(n2)$. Also, if the original graph G is connected, then G is also connected. However, nodes that are a few hops away in G can become very far apart in G. Relative neighbor graphs have an average node degree of 2.6.

3.5. GG: Gabriel graph

In the Euclidean plane, the Gabriel Graph (GG) connects point u and v if the disk having line segment uv as its diameter contains no other node than itself and the neighbor. Formally, the GG $G = (V, E)$ of a graph $G = (V, E)$ is defined as: Where $d(u, v)$ is the Euclidean distance between nodes u and v. The GG also maintains

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connectivity and has the same message and computational complexity of RNG.As it can be seen RNGs and GGs are very similar; they both remove every link to a neighbor node that could be reached through another neighbor. Distributed implementations of the RNGs and GGs only require nodes to share their locations with their neighbors and test these conditions to verify each edge in order to determine the minimal set of neighbors. Although these two graphs have low message complexity (*O (n)*), their node degree can be as high as *n* - 1. If the node degree is not upper bounded, bottlenecks may exist in the communication graph. Shows how these techniques, although very similar, produce different final topologies. In the Figure, the weights on the edges are given by the Euclidean distance between the respective nodes.

4. PERFORMANCE METRIC AND EVALUATION PARAMETER IDENTIFIED

In order to provide comparison among topology control alternatives, the following Performance metrics will be chosen. Some of them are exclusive to the construction or the maintenance processes

- **Number of active nodes:** This metric measures the quality of the selection policy for nodes. In addition, the amount of active nodes selected by the algorithm has a direct impact on the lifetime of the network.
- **Number of messages:** This metric shows the overhead of the protocol in terms of message complexity, which is also related with the scalability of the protocol and the energy consumption.
- **Ratio of energy spent:** This metric shows the cost of the protocol in terms of energy; in other words, how much energy is spent in the execution of the protocol.
- **Ratio of covered area:** This ratio is important for comparing coverage-oriented protocols in order to compare effectiveness of their selection policies.
- **Network lifetime:** This metric is useful especially in comparing topology maintenance Protocols, and shows the behavior of some of the previously mentioned metrics in the time domain, in order to obtain an average behavior of the use of the resources in the network in the long run[32][33].

The evaluation of topology control protocols will be performed in different scenarios, in order to obtain a general idea of the behavior of the protocols under certain conditions. The list of factors that were used to define the different scenarios is the following:

- **Number of nodes:** This parameter determines the size of the topology. The variation of this parameter helps to determine the scalability of the protocols. The network sizes used on the experiments will be varied based on the evaluated metric, from very small topologies with only 5 nodes, to very dense topologies with 1000 nodes.
- **Side of the area L:** This parameter defines the size of the deployment area. The area is assumed to be a square of side L . This factor varied between 50 and 500 meters, depending on the definition of each particular experiment.
- **Communication range Rc:** This parameter is very useful because it has an implication in other parameters like average node degree. The levels of this factor were calculated mostly using the Critical Transmission Range (CTR) formula. The CTR is the minimal radius that produces a connected topology given the size of the network and the area side L.
- **Sensing range Rs:** This parameter is important determining the area of coverage of a single node. The levels of this factor will be statically defined as a certain ratio of the side of the area L.
- **Node location distribution:** The distribution of the nodes in the area plays a very important role in the performance of the protocols. Even though many assume uniformly random distribution, some require specific densities in every section of the deployment area.
- **Network load:** The amount of messages that every active node will be sending during the operation of the network. This could be constant and periodic, or could be variable depending on the occurrence of an event. All experiments assumed a network load of 1 message every 10 seconds per active node.
- **Packet size:** All experiments use two different message sizes: short messages, assumed to be control packets of 25 Bytes long, and long messages, assumed to be data or special long control packets of 100 Bytes long.
- **Initial energy:** This parameter represents the initial energy reserve that a node has at the beginning of the simulation. The value assumed for this parameter is 1 Joule per node, as in. This value is considerably small compared with the real amount of energy in the battery; however it will be selected for convenience in order to reduce the simulation time.

5. CONCLUSIONS

In this survey paper, we have reviewed two major topology issues in WSNs, namely topology awareness and topology control. Topology awareness problems construct 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 individual applications. 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. 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

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delivery, including queries, sensing data and control messages.

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