network should be efficient in terms of lossless data transmission and the longer lifetime to cover the large monitoring area of interest of the structure [10]. The problems of the SHM system do not completely satisfy by the existing WSN network. To address those issues, Wireless Intelligent Sensor and Actuator Network (WISAN) has been proposed as an alternative [11]. The goal of this work is to design and development of large area sparse and dense topology WSN and measure the lifetime of those networks using the Theory of Geometric Random Graph approach (TGRG). The lifetime related parameters of the dense and sparse topology sensor network monitoring system have studied to extend the monitoring system lifetime in building structural health. Four different performance metrics are considered to measure the lifetime of the dense and sparse topology monitoring network and those performance metrics are: number of active node, number of active nodes reachable from sink ,communication covered area, sensing coverage area. The organization of the paper is as follows. Section 2 describes research background. Section 3 contains the dense and sparse topology sensor network simulation model. Section 4 describes the experimental test result of the dense and sparse topology sensor network. Section 5 provides the comparison result of the dense and sparse topology sensor network in terms of lifetime. Section 6 outlines the summary and conclusion of the experimental results for the proposed model.

WSNs are increasingly used for SHM. The structural health of the building needs to continuously monitor using sensors placed at various locations on the structure [4]. In recent years, SHM is an important area in continuous monitoring applications that has received increasing research interest [1]. Various studies have shown that the cost of a monitoring system for structural health associated with disasters are much lower compared with the economic losses by means of providing early precautions to avoid major calamities. Present methods of structural monitoring system are difficult to install and costly to maintain. Sensor installation costs may vary for small-scale structures $1000-$5000 per sensor and for large-scale structures $27000 per sensor [26]. Therefore, there is a need for a monitoring system that could automatically monitor a building’s structural health. Topology construction protocol is a potential candidate that can reduces the topology of the sensor network nodes energy, saves node energy, and prolongs the network lifetime. In this study, the lifetime of the dense and sparse topology sensor network has been investigated in monitoring building structural health using Theory of Geometric Random Graphs approach. The practice of SHM suffers from large coverage area information with lifetime of the monitoring system. Research review has been shown that, the problem of monitoring system can be addressed by modifying the monitoring system using WSN technique. However, the challenge arise to select an optimum topology construction protocol to fulfil the current needs in the WSN monitoring network because every system has its own requirements. The goal of this study is to develop an improved WSN monitoring system.

2. Research Background

The use of sensing technology is steadily increasing in buildings structural health monitoring. Usually, nodes with sensors have been used to collect the sensor data. Sensor nodes transmit their own sensed signal to the respective base station. Traditionally, the data collection system that connects the sensor nodes to the base station is a wired system. Wire-based data collection systems have the greatest monitoring system longevity. However, the wire-based data collection system has been lost popularity due to the several reasons such as a higher installation cost for a small period of usage. Noticeably, the wireless sensor systems for collecting sensor data still better performance compared with wired systems [12]. Hazard taxation has been designed to determine the structural risk due to the natural phenomena such as seismic activity, mudslides, etc. In the case of SHM systems, many sensors have been placed on the grave location in the service region. The most common technique has been used to fix the dynamic factors is the way to count the earthquakes inside buildings under constant surveillance, but such systems are expensive. Recently, the electromagnetic field (EMF) based sensing mechanisms become another kind of technique for monitoring structural health. The major benefit of the EMF method its high precision compared with the typical accelerometers method. This measurement technique based on microwave radar and can be applied in all weather conditions, and has been established as a dominant system to measure the different kinds of structural acceleration [13]. Durable SHM systems have been demonstrated in different countries, but the real-time measurement still facing many challenges shown by the author [9, 23]. The lifetime of a SHM system is gradually decreases due to its several drawbacks such as strong earthquakes, corrosion, heavy traffic, etc. According to the American Society of Civil Engineering, more than 26% of bridges experience a drop in efficiency over time. However, the wire-based sensor system is more expensive and cannot be effectively used to monitor the large structures. WSNs allow a dense network to pinpoint the structural health problem based on fault tolerance.

Many researchers have been shown that various issues arise with WSNs among those Interference and noise becoming a vital concern for sensor network communication systems [14]. Setting up a health monitoring system for large-scale building structures, which require a large number of sensor nodes. The placement of these sensors is great significance for such distributed application of sensor node in the SHM system [15]. To cover the large geographical civil infrastructure, scalability of the WSN is the most important issue. Sensor coverage area defines the complexity of the scalability to cover the whole service area. Topology construction protocols are used to cover the area of monitoring interest using topology construction protocol. Below Table 1 shows the features of topology construction protocol:

Table 1. List of major features, strength and weaknesses of all the relevant protocols

Protocol	Features	Strength	Weakness	Reference
EECDS	Work on “grow a tree” approach with Prim’s algorithm. Use coloring approach.	Energy efficient. Built maximum independent set.	More message complexity. Costly in terms of message overhead.	(Yuanyuan et al. 2006; Makki 2010)
CDS-Rule-*K*	Pruning based mechanism. Use Connected Dominating Set under Rule K- algorithm	Unnecessary nodes are pruned out. Work start with non-connected topology.	Complexity in message. Computation complexity.	(WU & Li 1999; Dai & Wu 2004; Wu et al. 2006)
K-neigh	Neighbor based technique. Create connected topology with the smallest necessary set of neighbors.	Provide relatively good solution for accurate Catesian co-ordinate problem. Localized information is not always necessary.	Decisions depend on the probability of selecting appropriate neighbor. Only applicable for uniformly or Poission distributed node.	(Blough et al. 2003; Xue et 20014; Gupta 20015)
A3	Simple, energy-efficient and distributed. Growing tree based mechanism.	Synchronization mechanism is not required. Works in a distributed manner with scalability. Able to turnoff unnecessary nodes.	Less reliable with fewer node. Leave more uncover space when use small number of active to save node energy.	(Pachnanda 2010; Wightman & Labrador 2009)
A3-*Cov*	Used to address coverage area problem. Build a back-bone network that guarantees the network connectivity.	Extend the coverage area whilst saving energy. Active node in the back-bone. Specially care-about sensing coverage area.	Non-localize connected Backbone. Sensing coverage area is not very large from observation of the empirical.	(Cardei & Wu 2006; Whightmam & Labrador 2011)

Scalability of the WSN provides the adjustment flexibility with infrastructure for monitoring structural health by adding a new sensor node in the network and also defines the higher precision of damage detection [16]. A recent number of papers indicate that the artificial neural network has been considered for monitoring and detection of structural damage. The fault detection system consists of vector of the system as input and desired the fault classification as output. To bring the desired output, the internal structure of the neural network has been modified at presentation of the data level. When the neural network outputs have required properties over the whole training set, this iterative method has removed [17]. The authors believe that, to address the lifetime related problem, the application of the dense and sparse topology sensor network in high-rise building SHM overcomes the monitoring system lifetime related problem.

3. Approach Description

This section presents the energy model that is used to simulate the dense and sparse topology sensor network as energy model. The analytical and simulation model of the dense sparse topology sensor network is performed using Topology construction protocol and no topology maintenance.

3.1. Energy model

It is important to include a model to drain the sensor node energy every time they perform in any action in order to perform the lifetime of the monitoring network. The energy model used to model the node energy consumption is based on Equation 1 and 2, introduced in [18]. Mainly, the above model has been designed on the receiving and transmitting node data.

$$E_{Tx} = E_{elec} + E_{amp} * R^2_{comm} * \pi \qquad (1)$$

$$E_{Rx} = E_{elec} \qquad (2)$$

Where, E_{Tx} is the required transmit signal energy to transmit 1 bit and is the receiver energy to receive same number of bit like. The energy of the electronics component of the radio signal is denoted by and amplifier radio energy is represented by. The second terms present the square area of the transmission range that is achieved by the radio signal. Due to the simplicity of the energy model, it has been frequently used in the WSNs network. It is supposed that, at ideal condition the energy consumption is negligible. The energy model parameters values are summarized in Table 2.

Table 2. Energy model parameters mapping

Initial source energy	1 Joule
E_{elec}	50 nJ/bit
E_{amp}	10pJ/bits/m2

3.2. Analytical model of dense and sparse topology sensor network

This section presents the development model of the dense and sparse topologies sensor network. Theory of Geometric Random Graphs approach is used to develop both dense and sparse topology sensor network using topology construction protocol. The evaluations model and parameter definition of the dense and sparse topology scenarios for each set of experiments are presented in this section.

3.2.1 Dense topology sensor network model

In dense topology sensor network, the maximum number of each sensor node to all other sensor node is near the total number node use in the network. When each sensor node is directly connected to all other node, the network is called fully connected network. Fig. 1 shows the example of dense topology sensor network for *N=9* number of sensor nodes. It has seen that, the below Figure 1 shows the fully connected dense topology sensor network scenario, since all the nodes in the network connect with each other's directly. Fig. 2 represent the functional block diagram of the dense topology sensor network. The deployment block deploy the predefine set of wireless sensor node with fixed area of monitoring interest. In the deployment block, communication radius, sensing radius, number of sink, node energy distribution, energy model and communication model are defined. The Atarraya block contains the following options: (i) TC (Topology Control) protocol; (ii) TM (transmission maintenance) protocol; (iii) Sensor and data protocol; (iv) routing protocol; (v) node mobility model. The visualization block visualize the deployment area and nodes stats describe the state of the node. TC theoretical block define the topology of the monitoring network. To deploy the dense topology sensor network, *CTR* of the dense network define by the *CTR* function. The report block converts the machine readable data to the human readable format.

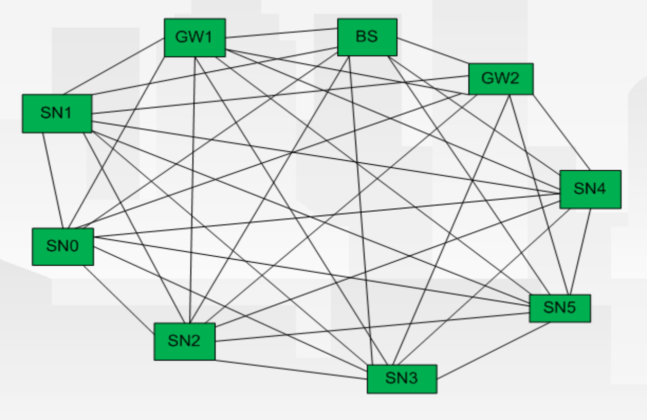

Figure 1. Dense topology sensor network scenario

TGRG approach [19] is used to provide an analytical solution to the communication range problem with high probability (w.h.p.) and produces a connected topology under some consideration. Consider, *n* is the number of sensor nodes are uniformly distributed in a square area *L*. The nodes organization is uniformly distributed means all the sensor nodes are equal distance in the monitoring area. The Penrose formula [20] is used to determine the critical transmission range (*CTR*) value for the dense topology sensor network. The Penrose formula only applies to the dense topology sensor network. The accuracy of the Penrose formula is determined by the Giant Component (GC) test [22]. Table 3 shows the experimental setup of dense topology sensor network. The number of nodes define the density of the monitoring network. Initial *CTR* defines the initial value of the monitoring network. The *CTR* step defines the increasing value from the initial *CTR*. The number of topologies of monitoring network is predefined using topology parameter. The area side of the monitoring network defines the deployment area of the dense network. The giant component is a very well-known effect to compute the connectivity of the monitoring network. The maximum component, connected topology, average node degree is considered as a giant component of the SHM network. These performance metrics are calculated using a *CTR* function of the SHM network.

Table 3 Experimental setup for dense topology sensor network

Network Parameters	Assumption Value
Number of Nodes	100
Communication radius	100m
Sensing radius	20m
Deployment area	600mx600m with central 300mx300m
Node energy distribution	1000mJ (constant)
TC protocol	*A3, CDS-Rule-K, EECDS, K-neigh, A3-Cov*
TM protocol	Without topology maintenance
Sensor & data protocol	Simple S & D protocol
Routing/Forwarding protocol	Simple Forwarding
Performance metrics	Number of active nodes, number of active nodes reachable from sink, covered area for communication, covered area for sensing.
CTR modelling [24]	$CTR_{dense} = \sqrt{\frac{\ln n + f(n)}{n\pi}}$ $\lim_{n \to \infty} f(n) = \infty$

3.2.2. Sparse topology sensor network model

In sparse topology sensor network, the minimum number of link is connected compared with dense topology sensor network. This type of sensor network topology can be found in more difficultly to create network link between nodes. For example, below Fig. 2 shows the sparse topology sensor network for *N=9* number of sensors nodes, in which a minimum number of links is seen to connect the sensor node with each other and also base-station.

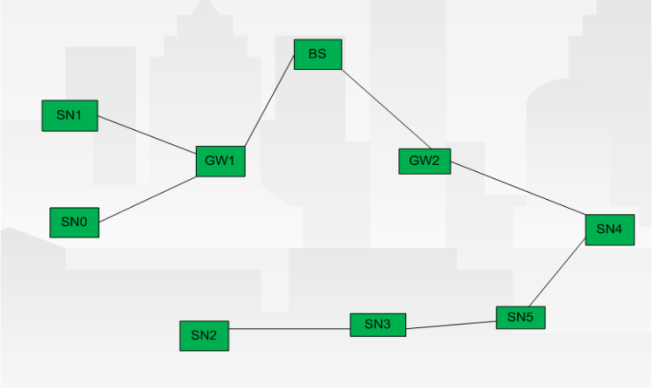

Figure. 2 Sparse topology sensor network scenarios

Table 4 shows the parameters setup for lifetime analysis of sparse topology sensor network. The parameter design value of the sparse topology sensor network describe in the Table consists of major parameters interest in terms of lifetime performance metrics.

Table 4. Experimental setup for lifetime analysis of sparse topology sensor network

Network Parameters	Assumption Value
Number of Nodes	100
Communication radius	100m
Sensing radius	20m
Deployment area	600mx600m with central 300mx300m
Node energy distribution	1000mJ (constant)
TC protocol	*A3, A3-Cov, CDS-Rule-K, EECDS, K-neigh*
TM protocol	Non Isolated Sink
Sensor & data protocol	Simple S & D protocol
Routing protocol	Simple Forwarding
Performance metrics	Number of active nodes, number of active nodes reachable from sink, covered area for communication, covered area for sensing.
Model assumption	For one dimensional, $CTR = k\frac{l \log l}{l}$ [20] For multidimensional, $CTR = k\frac{l^d (\log l)}{n}$ [20] Where, d= 2, 3,…….

4. Experimental test results

This section presents the experimental test result of the dense and sparse topologies sensor network. Topology construction protocol and no topology maintenance protocol are used to develop both dense and sparse topology sensor network. The evaluation model and parameter definition of the dense and sparse topology scenarios for each set of experiments are presented in this section. Section 4.1 and 4.2 describes the dense and sparse topologies experimental test result for lifetime measurement.

4.1. Dense topology test results

In this section, the experiment results related with the dense topology monitoring system is presented to determine the lifetime using topology construction protocol. The comparison results of the *EECDS*, *CDS-Rule-K*, *K-neigh*, *A3* and *A3-Cov* topology construction protocols are presented with considered performance metrics. In those experiments, the dense topologies sensor network are defined in which the communication radius is calculated based on the *CTR* formula of Penrose-Santi [20]. The implementation of those protocols were coded and tested using Atarraya tool, which is designed with the purpose of testing topology construction algorithm. Four main performance metrics were utilized to assess the lifetime of dense topology monitoring system: 1). Number of active nodes; 2) number of active nodes reachable from sink; 3) communication section coverage area; 4) sensing coverage area. The first and second metrics shows with preserving network connectivity and coverage, how the topology construction protocol effectively reduce the amount of active node and reachable nodes from sink in the monitoring network. The others two metrics shows how efficiency of the topology construction protocols in terms of communication and sensing coverage area of the monitoring system.

Four sets of experiment are evaluated to define the dense topology monitoring system lifetime in this section. Section 4.4.1 presents the first experiment of the dense topology sensor network with considering number of active node in terms of network transmission time. Section 4.1.2 describes the experiment 2 to define number of active node reachable from sink of the monitoring network. This experiment compare the topology construction protocols result to provide the better topology sensor network and observe how the network behaviour with high density nodes. Section 4.1.3 describes the experiment 3 to define which topology construction protocols offer the better lifetime of the monitoring system in term of communication network coverage area. Sections 7.4 describe the experiment 4 that use the sensing coverage area of the network with considered topology construction protocols those are used for experimental purpose. This experiment observes that how the sensing coverage area of the network behaves with topology construction protocols with high density nodes in term of network transmission time.

4.1.1. Experiment 1- Number of active nodes

The main goal of this experiment is to compare the topology construction algorithm in term of number of active nodes by increasing the transmission time of the network. Those topology construction protocol work based neighbor’s node information. Therefore, it is important to measure the performance of topology construction protocol with active number of nodes in the network. As much as possible to keep lower number of active node in the network prolong the network lifetime. Fig. 3 show the number of active nodes versus the lifetime of the network using *EECDS, K-neigh, CDS-Rule-K, A3,* *A3-Cov* topology construction protocol with energy and time based criteria and no topology maintenance at all. The trends are clear regardless of the topology construction algorithm used, *K-neigh* and *A3-Cov* improve the lifetime of the monitoring network compared with *EECDS* and CDS-Rule-*K* topology construction protocol in term of number of alive nodes performance metrics. The *K-neigh* approach produce best result with minimum number of active nodes compare to others. This result is expected due to ability to create preliminary version of the *K-neigh*, and add or removes neighbour nodes to obtain a better approximation to optimal *CDS* in the network.

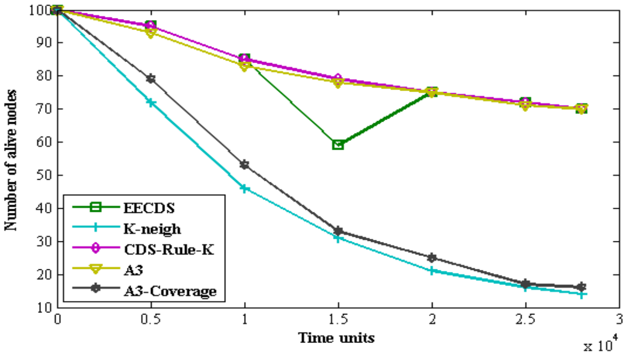

Figure 3. Network lifetime for number of active nodes

The conclusion of this experiment is that the *K-neigh* topology construction protocol approach is the best number of active nodes in the network for monitoring building structural health. In the case of number of active nodes, all protocols provide higher value at initial operation of the monitoring network. The *K-neigh* protocol improve the number of active nodes that means life time of the network over *A3-Cov* topology construction protocol that improve the network lifetime until the network dies at 2.8 time units. After that, the number of active nodes in case of *CDS-Rule-K* protocol degrades the system performance compared with *A3* and *EECDS* protocols. But, the *K-neigh* protocol result always dominant *A3-Cov* and *K-neigh* protocols until the network unavailable. The *K-neigh* topology construction protocol produced best performance to extend the monitoring system lifetime with preserving coverage area and connectivity.

4.1.2. Experiment 2- Number of reachable nodes from sink

The main goal of this experiment is to compare the results produced by topology recreation protocols in term of number of reachable nodes from sink performance metrics while fixed communication range of nodes 100m and 100 numbers of nodes uniformly distributed in the area of 600m×600m deployment area. This experiment is important to show how much amount of active nodes can be reachable from sink in dense topology and how the resource usage depends on the number of active nodes reachable from sink. In this case, higher number of reachable node is better for coverage area with detection of event of sensor nodes.

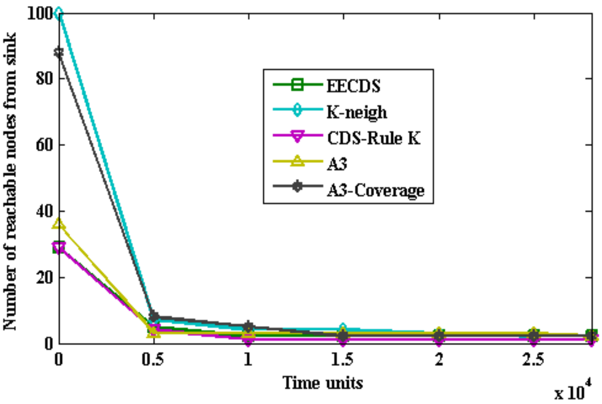

Figure 4. Network lifetime for number of reachable nodes from sink

Fig. 4 shows the performance of topology construction protocol technique in dense network in term of number of reachable nodes from sink. The behaviour of higher number of node can be explained by the fact that having more active nodes reachable from the sink consumes more energy because it generates more messages that travel to the sink. Therefore, less number of active node from sink is expected as much as less is the better performance of the topology construction protocols. The *A3* protocol improves the lifetime of the network compared with *EECDS* and *CDS-Rule-K*. It is observe that, the performance of *EECDS* protocol continues to be very close with CDS-Rule-K topology construction protocol. The *A3-Cov* protocol shows the improvement, when *EECDS*, *CDS-Rule-K* degrade the system performance compare to *A3-Cov*. While *K-neigh* mechanism extend the network lifetime, the *A3-Cov* provide very close continuously compared with *K-neigh*. This result is expected due to *CDS-Rule-K* has ability to connect with minimum number of neighbour set and transmission power.

The conclusion of this experiment is that, the *A3* and *CDS-Rule-K* protocols are the best policy for number of active nodes reachable from sink in monitoring structural health. Result shows that all topology construction protocols need a similar amount of active nodes reachable from sink from 0.5 time units until network vanish. Before time units 0.5 of the network, the number of active nodes reachable from sink of *K-neigh* protocol is 100% but *A3-Cov* provides 12%. After that, *A3-Cov* provides better result of number of reachable nodes from sink compared with *K-neigh* until the network dies. The behaviour of *A3-Cov* protocol can be explained by the fact that having more number of active nodes reachable from sink not only consume more energy, but also generate more messages and travel to the sink. It is also important to mention that this experiments is performed to show that the various topology construction protocol have an impact on the number of active nodes reachable from sink and lifetime of the network. The results show, how the *CDS-Rule-K* topology construction mechanism provides better number of active nodes and network lifetime compared with *EECDS*, *A3-Cov*, *A3*, *K-neigh*, mainly because *CDS-Rule-K* can connected available resources in the network.

4.1.3. Experiment 3- Communication covered area

The main goal of this experiment is to compare the results using the topology construction approach in term of communication coverage area while the communication range of nodes 100m and 100 numbers of nodes uniformly distributed in the same area which was shown in experiment 2. This experiment is important to show how much coverage area is gained in dense topologies network and how the resource usage depends on the communication coverage area of the network. After the execution of the topology construction algorithm, the active nodes in the network determine the communication coverage area. To cover the deployment area for monitoring interest area of structural, the communication coverage area is expected as much as greater. Fig. 5 shows the network lifetime experimental results using *EECDS*, *K-neigh*, *CDS-Rule-K*, *A3*, *A3-Cov* topology construction protocol in dense network in term of ratio of communication coverage area. The covered area for communication of *EECDS* protocol improves the coverage area and lifetime of the network, while *CDS-Rule-K* provides very similar result and slightly better compare to EECDS. The *A3-Cov* protocol extend the network life time, when *K-nigh* topology construction protocol degrade the system performance which is lightly comparable to *A3-Cov*. The *A3* protocol approach produce the better coverage area; while the performance of *A3-Cov* technique shows also shows similar and initially better compared with *A3*. In terms of communication coverage area and network lifetime: *A3* is still better compared with *A3-Cov*. This result is expected because *A3* protocol is energy efficient topology construction protocol that has ability to find sub-optimal connected dominating set to turn off unnecessary nodes.

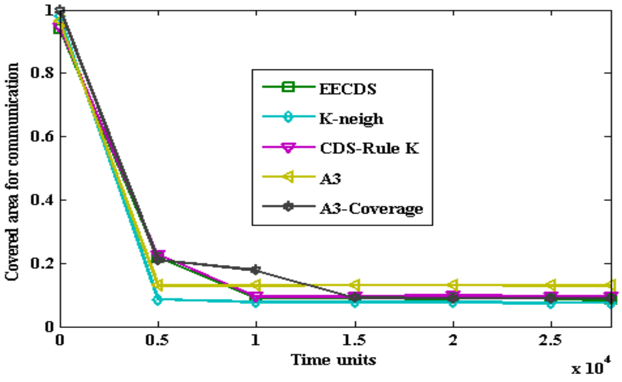

Figure 5. Network lifetime for communication coverage area

The conclusion of this experiment is that, the *A3* topology construction protocol approach is the best communication coverage policy for monitoring area of interest. In the case of communication coverage area, the *A3-Cov* protocol provides a communication coverage ratio of 100% initial operation of the monitoring network. Although, the *K-neigh* approach provides 98% ratio of the communication coverage area for monitoring that is 2% smaller than *A3-Cov* protocol initially. In the performance place, *A3* and *CDS-Rule-K* attain the third and fourth place according to the highest number of sensing gain which are 96% and 94% respectively at the initial operation of the network. The *EECDS* protocol attain 5th place about 93% of the communication coverage area initially and after that the result is continue to be very close to the *CDS-Rule-K*. From 0.5 time units until network die, the *A3* protocol provides better result compared with others topology mechanism those are similar result.

4.1.4. Experiment 4- Sensing coverage area

The main goal of this experiment is to compare the experimental result of topology construction algorithm technique in dense topology sensor network in term of sensing coverage area. After executed the topology construction algorithm, the sensing coverage area determines monitoring area interest. To cover deployment area for monitoring structural health, the sensing coverage area is expected as much as greater near to interest area. Therefore, it is necessary to measure how munch sensing area can cover by the topology construction protocol. Fig. 6 show the ratio of sensing covered area versus network lifetime of the network using *EECDS*, *K-neigh*, *CDS-Rule-K*, *A3*, *A3-Cov* protocols without topology maintenance over time and energy based triggering criteria. Result shows that, all protocols provide non-linear decreases. The *EECDS*, *CDS-Rule-K*, *A3* protocols results are similar to each other's. *EECDS*, *CDS-Rule-K*, *A3* protocols degrades system performance compared with *K-neigh* and *A3-Cov* protocols. *A3-Cov* and *K-neigh* protocols improve coverage area and network lifetime when others considered protocols provides the small coverage area in the monitoring network. Result shows that, *A3-Cov* protocol produce the greater ratio of sensing area compared with *K-neigh*. This result is desire because it has ability to add extra nodes to provide extra coverage area for sensing with minimum complexity and node energy.

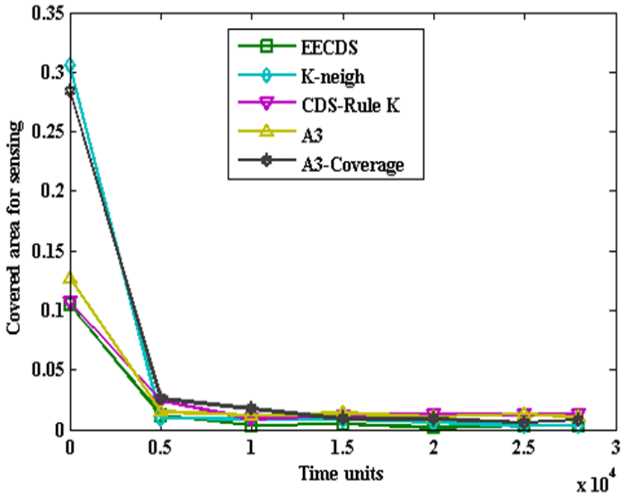

Figure 6. Network lifetime for sensing coverage area

It is conclude that *A3-Cov* topology construction protocol approach is the best coverage policy for monitoring structural health. In case of sensing coverage area, the *A3-Cov* protocol provides a coverage ratio of 28% initial operation of monitoring network. Although, *K-neigh* approach provides almost 30% ratio of the sensing coverage area which is 2% greater than *A3-Cov* protocol initially. Between 0 to 0.5 time units, the sensing coverage ratio decay and *A3-Cov* lead the *K-neigh* protocol. After decay *A3-Cov* always dominant until the network dies at 2.8 time units. On the other hand, initially A3 protocol provides 12% sensing coverage ratio and then decreases until the network transmission out. Initially, *EECDS and CDS-Rule-K* gain same 10% sensing coverage ratio and after that the results continue to be very close with each other until 0.5 time units. From 0.5 to 2.8 time units, the sensing coverage of *CDS-Rule-K* protocol dominant the *EECDS*-approach. Between 0.5 to 2.8 transmission times, all protocol provides the similar sensing coverage area and it is hard to define the better topology construction protocol. The trade-off between *A3-Cov* and *K-neigh* approaches is very clear: although *A3-Cov* covers 2% less sensing area than *K-neigh* initially, after that its exhibit better coverage area compared with *K-neigh*. This behaviour can be explained by the fact that having more sensing area not only consume more energy, limiting their use for future, but also more energy because of the number of messages generate travel to the sink and usage resources from all nodes in the path. The results show how *the A3-Cov* topology construction mechanism provide a better sensing coverage area and network lifetime compared with *EECDS, K-neigh, A3, CDS-Rule-K*.

4.2. Lifetime results of sparse topology sensor network

In this section, experiments result related with the lifetime of sparse topology network are presented using topology construction protocols. The comparison results of the *EECDS, CDS-Rule-K, K-neigh, A3* and *A3-Cov* topology construction protocols are presented also. In these experiment, the sparse topology sensor network is define first and the communication radius is calculated based on the *CTR* formula of Penrose-Santi [20]. Same number of performance metrics are considered to assess the lifetime of the sparse topology sensor network those are: 1). Number of active nodes; 2) number of active nodes reachable from sink; 3) communication coverage area; 4) sensing coverage area.

The four set of experiments are evaluated to define the sparse topology sensor network lifetime. Section 4.2.1 present the first set of experiment which consider the number of active nodes of the monitoring system to determine network lifetime in term of transmission time. Section 4.2.2 describe the experiment 2 that determine how much of active nodes reachable from sink with considering high density network nodes and topology construction protocols. Section 4.2.3 describes the experiment 3 that compare the topology construction protocols result in term of monitoring network coverage area. This experiment observe that which topology offer better monitoring system lifetime in term of communication coverage area. Section 4.2.4 describe the experiment 4 determine the sensing coverage area of the monitoring network with high density network nodes. This experiment observes that how the sensing coverage of the monitoring network behaves with considered topology construction protocols. The sensing coverage area expected always large value as much as possible to near the area of monitoring interest.

4.2.1. Experiment 1- Number of active nodes

Fig. 7 show the number of active nodes versus the lifetime of the network using *EECDS, K-neigh, CDS-Rule-K, A3, A3-Cov* topology construction protocol with energy and time based criteria. The trends are clear regardless of the used topology construction algorithm, *A3-Cov* and *A3* improve monitoring system lifetime compared with *K-neigh* topology construction protocol in term of number of active nodes performance metrics. The *K-neigh* approach produced the best result because it’s produce the minimum number of active nodes with preserving the network connectivity and prolong the network lifetime. On the other hand, the performance of *A3-coverage* technique shows continue to be very close with *K-neigh.* This result is expected due to ability to create maximum independent sets in the first phase and during second phase select gateway nodes to connect the independent set.

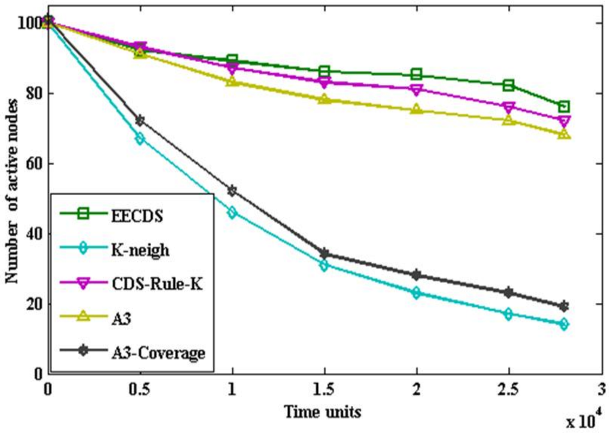

Figure 7. Network lifetime for number of active nodes

The conclusion of this experiment is that, the *K-neigh* topology construction protocols approach is the best number of active nodes in the network for monitoring structural health. Although, *EECDS* topology construction protocol provide higher value compared with other topology construction protocol, due to its message complexity it's not suitable for large area monitoring system.

4.2.2. Experiment 2- Number of reachable nodes from sink

Fig. 8 shows the performance of the topology construction protocol without any maintenance technique in sparse topology sensor network in term of number of reachable nodes from sink. The results shows in Fig. 12, is not similar to the ones shown in experiment 1. Before 0.5 time units, *A3*, *CDS-Rule-K*, *EECDS* provides almost similar result but after 0.5 time unit, the result become closest with each other. The *K-neigh* protocol improves the lifetime of the network compared with *A3*, *EECDS and CDS-Rule-K*. It has been seen that, the performance of *K-neigh* protocol continues to be very close to *A3-Cov* topology construction protocol. The *A3-cov* protocol shows the improvement when *EECDS*, *CDS-Rule-K*, *A3* degrade the system performance compare to *A3-Cov*. The *K-neigh* mechanism extend network lifetime, while *A3-Cov* provide better result continuously compared with *K-neigh*.

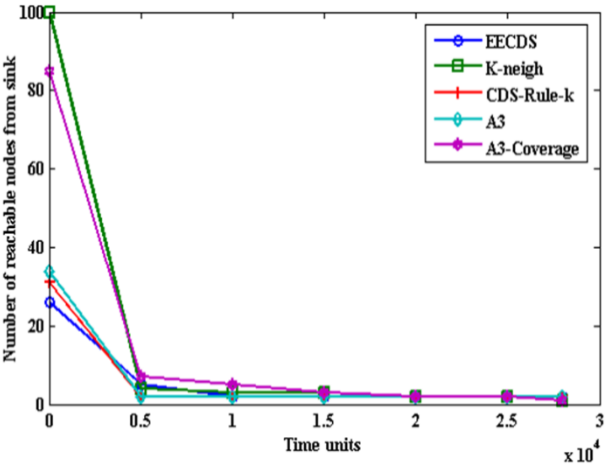

Figure 8 . Network lifetime for number of reachable nodes from sink

Result shows that all topology construction protocols need a similar amount of active nodes reachable from sink from 0.5 time units to until network dies. Before time units 0.5, the number of active nodes reachable from sink of *K-neigh* protocol is 100% but *A3-Cov* provides number of active nodes reachable from sink 85%. After that *A3-Cov* provides better number of reachable nodes from sink compared with *K-neigh* until the network dies. The EECDS generate the less number of active nodes consequence of less message complexity. Therefore, conclusion of this experiment is that *EECDS* protocol is best policy for number of active nodes reachable from sink.

4.2.3. Experiment 3- Coverage area for communication

After executed topology construction protocol, the active nodes in the network determine the communication coverage area. The communication coverage area is expected as much as greater to cover the deployment area for monitoring area of interest. Fig. 9 shows the network lifetime results using *EECDS*, *K-neigh*, *CDS-Rule-K*, *A3*, *A3-Cov* topology construction (*TC*) protocol in sparse network in term of ratio of communication coverage area performance metrics. The coverage area for communication of *EECDS* protocol improves the coverage area and lifetime of the network, while *CDS-Rule-K* provides very similar result and slightly better compared with *EECDS*. The *A3* and *K-neigh* protocol provides the similar result for network life time. When *CDS-Rule-K* and *A3* topology construction protocol degrade the system performance smaller amount compared to *A3-Cov*. The *A3-Cov* protocol approach produce better performance compared with others. In terms of communication coverage area and network lifetime: *A3-Cov* is still better.

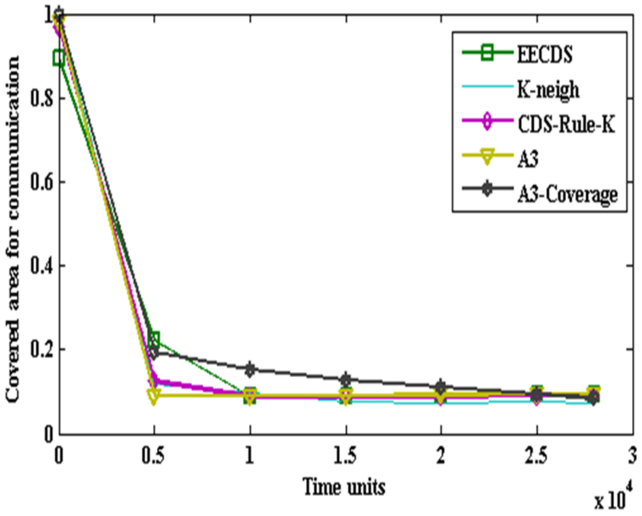

Figure 9. Network lifetime for communication coverage area

The conclusion of this experiment is that the *A3-Cov* topology construction protocol approach is the best communication coverage policy for sparse topology sensor network in monitoring structural health. In the case of communication coverage area, the *A3-Cov* protocol provides a communication coverage ratio of 100% initial operation of the monitoring network. The *A3* approach provides 98% ratio of the communication coverage area for monitoring that is 3% smaller than *A3-Cov* protocol. In third and fourth place are the *CDS-Rule-K* and *EECDS* according to the highest number of sensing gain which are 97% and 89% respectively at the initial operation of the network. The *K-neigh* protocol attained about 100% of the communication coverage area initially and after that degrades the system performance compared with *A3-Cov* protocol. From 0.5 time units until network dies, the *A3-Cov* protocol provides the better result compared with others.

4.2.4. Experiment 4- Coverage area for sensing

Fig. 10 show the ratio of sensing covered area versus the lifetime of the network using *EECDS*, *K-neigh*, *CDS-Rule-K*, *A3*, *A3-Cov* protocols using no topology maintenance over time and energy based triggering criteria in sparse topology sensor network. Result shows that, all protocols provide the non-linear decrease. The results shows, *EECDS*, *CDS-Rule-K*, *A3* protocols are similar to each other's. The *EECDS*, *CDS-Rule-K*, *A3* protocols degrades the system performance compared with *K-neigh* and *A3-Cov* protocols. An *A3-Cov* and *K-neigh* protocols improve the sensing coverage area and network lifetime while other considered protocols provides the small coverage area in the monitoring system. Result shows that, *A3-Cov* protocol produce the slightly better ratio of sensing coverage area compared with *K-neigh*. This result is desired because, it has ability to add extra nodes to provide extra coverage area for sensing with minimum complexity and node energy.

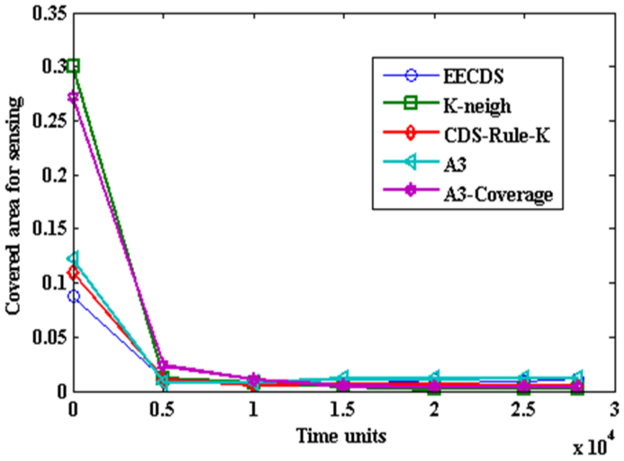

Figure 10. Network lifetime for sensing coverage area

The conclusion of this experiment is that the *A3-Cov* topology construction protocol approach is the best coverage policy for monitoring structural health. In the case of sensing coverage area, the *A3-Cov* protocol provides a coverage ratio of 27% initial operation of the monitoring network. Although, the *K-neigh* approach provides 29% ratio of the sensing coverage area for monitoring that is 2% greater than *A3-Cov* protocol initially. After that, *K-neigh* sensing coverage area decays and *A3-Cov*e area always dominant until the network dies at 2.8 time units. On the other hand, *A3* protocol provides a sensing coverage ratio of 12% initially, and then decays until the network dies at 2.8 time units. Initially, *EECDS and CDS-Rule-K* gain the sensing coverage ratio 10% and 8% after that the results continue to be decreases until 0.5 time units. From 1 to 2.8 time units, the sensing coverage of *EECDS* protocol dominant *CDS-Rule-K* approach. Between the time units 0.5 until 2.8, *A3* provide the better topology construction protocol based on this range. It has been conclude that *A3* topology construction mechanism provides a better sensing coverage area and network lifetime compared with others topology construction protocol.

5. Result Comparison of dense and sparse topology network

In this section, the results of all experiment that related with the lifetime of the WSN monitoring system are compared using considered performance metrics, in both dense and sparse topology sensor network. The life time related experimental results of the dense and sparse topology sensor are compared using topology construction protocols in terms of number of active nodes, number of active node reachable from sink, covered area for communication, covered area sensing using numerical data to more preciously define of protocol performance.

Table 5 shows the comparison result of the dense and sparse topology sensor network in terms of number of active nodes life. Comparison table show that, the dense topology sensor network exhibit better result compare to the sparse topology sensor network based on minimum average value. Result also shows that, *K-neigh* dense provides (45.25) which is the better result compare to sparse *K-neigh* (45.75) in term of number of active nodes.

Table 5. Experiment 1: Number of active nodes

Topology	Protocols	Transmission Time			
		0	10000	20000	28000
Dense topology sensor network	*EECDS*	100	85	75	70
	K-neigh	100	46	21	14
	CDS-Rule-K	100	85	75	70
	A3	100	83	75	70
	A3-Cov	100	53	25	16
Sparse topology sensor network	*EECDS*	100	87	81	72
	K-neigh	100	46	23	14
	CDS-Rule-K	100	89	85	76
	A3	100	83	75	68
	A3-Cov	100	52	28	19

To better understand the comparison result of the dense and sparse topology sensor network, Table 6 shows the detail description of the result in terms of number of active nodes reachable from sink. Comparison results show that, the dense topology sensor network exhibit the better results compare to the sparse topology sensor network. Based on average minimum result, the sparse EECDS provides (7.75) better result compared with considered *CDS-Rule-K dense topology* (8) network construction protocols.

Table 6. Experiment 2: Number of active nodes reachable from sink

Topology	Protocols	Transmission time			
		0	10000	20000	28000
Dense topology network	*EECDS*	29	2	2	2
	K-neigh	100	4	3	2
	CDS-Rule-K	29	1	1	1
	A3	100	83	75	70
	A3-Cov	88	5	2	2
Sparse topology network	*EECDS*	25	2	2	2
	K-neigh	100	3	2	1
	CDS-Rule-K	31	2	2	2
	A3	34	2	2	2
	A3-Cov	85	5	2	1

Table 7 reveal the comparison result between dense and sparse topology sensor network which contain the details description of the experimental result in terms of communication coverage area. Average result show that, A3-Cov dense protocol draw 33.85%, where as 33.65% coverage area draw by sparse topology sensor network. Therefore, it can be concluded that, *A3-Cov* dense protocol exhibit better result than others.

Table 7. Experiment 3: Covered area for Communication

Topology	Protocols	Transmission time			
		0	10000	20000	28000
Dense topology network	*EECDS*	0.937	0.090	0.087	0.084
	K-neigh	0.980	0.077	0.076	0.073
	CDS-Rule-K	0.945	0.094	0.098	0.096
	A3	0.964	0.128	0.130	0.129
	A3-Cov	1	0.176	0.089	0.089
Sparse topology network	*EECDS*	0.895	0.089	0.090	0.091
	K-neigh	1	0.099	0.073	0.074
	CDS-Rule-K	0.970	0.087	0.088	0.089
	A3	0.983	0.090	0.091	0.094
	A3-Cov	1	0.152	0.111	0.083

The experimental results of both dense and sparse topology sensor network are presented in Table 8 with considering sensing coverage area performance metrics. Results show that, dense *K-neigh* (8%) protocols demonstrate the better results compare to sparse *K-neigh* (7.7%) and others considered topology construction protocols.

Table 8 Experiment 4: Covered area for sensing

Topology	Protocols	Transmission time			
		0	10000	20000	28000
Dense topology network	*EECDS*	0.104	0.003	0.001	0.003
	K-neigh	0.305	0.008	0.005	0.002
	CDS-Rule-K	0.106	0.008	0.012	0.013
	A3	0.126	0.011	0.010	0.010
	A3-Cov	0.284	0.017	0.008	0.008
Sparse topology network	*EECDS*	0.087	0.005	0.009	0.010
	K-neigh	0.299	0.007	0.001	0.001
	CDS-Rule-K	0.109	0.005	0.006	0.004
	A3	0.121	0.008	0.011	0.011
	A3-Cov	0.271	0.010	0.003	0.003

6. Summary and Conclusions

A distributed model has been derived for dense and sparse topology sensor network using critical transmission range formula. The lifetime metrics of the dense and sparse network topology sensor was analyzed using topology construction protocol. The topology construction protocol provides the reliable information to identify the optimum topology construction protocol for monitoring network. Various topology construction protocols were used to identify the better monitoring system. The developed monitoring system was tested using Atarraya java based tool.

Result shows that, the dense topology *K-neigh* provides the better result in term of number of active nodes compared with others considered dense topology construction protocols. In case of number of active nodes reachable from sink, sparse *EECDS* topology construction protocol provides the better result compared with other considered protocols. For communication coverage area, dense *A3-Cov* topology construction protocol better result and it would be a good choice for monitoring structural health. In case of sensing coverage area, *dense K-neigh* construction protocol proved itself better performance compared with others considered protocols. Finally, it has seen that, the dense topology sensor network is selected as an optimum lifetime topology construction for monitoring structural health compared with *K-neigh* protocol based on sensing criteria. It is believed that the results presented in this article provide a better understanding of lifetime comparison between dense and sparse topology sensor network in SHM application

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