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Performance Study of Collection Tree Protocol in Mobile Wireless Sensor Network

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ABSTRACT

The Mobile Wireless Sensor Networks (MWSN) are defined as the successor of Wireless Sensor Networks (WSN); geographically distributed autonomous mobile sensors for physical and environmental conditions monitoring. Mobile sensor networks are more flexible than static sensor networks as they can cope with rapid topology changes. Sensor networks are deployed by having their sensors collect information reliably and then relay the sensor readings to a central base station using wireless multi-hop transmission. Multi-hop routes within a rapid-changed topology requires a routing protocol that can adapt to network changes with an efficient communication mechanism among the nodes; to comply with the energy-constraint nature of the wireless sensor networks. Through significant simulation on this study using the AVRora simulator, the Collection Tree Protocol's (CTP) capacity to respond to MWSN's changing network topology was assessed by analysing the performance indicators; specifically, the average of packet loss and energy use of mobile nodes with different circumstances considering varied quantities of mobile nodes in the simulation region, with different velocities and network density. In several circumstances, the implementation of CTP in MWSN indicates a rise in energy usage because of broken linkages along with regular tree regeneration brought on by node mobility.

1. Introduction

Wireless Sensor Network (WSN) is built of several numbers of nodes, in which each of them is connected to one or several sensors. The distributed sensors shall collectively relay their data to a central point by means of the network. Mobile Wireless Sensor Networks (MWSN) are defined as the successors of WSNs with the sensor nodes being mobile. Mobile sensor networks are somehow more flexible than static sensor networks as they can be positioned in any framework and can cope with rapid topology changes. In Mobile Wireless Sensor Networks (MWSN), wireless routing techniques must adhere to two unique fundamentals: robust beaconing as well as data path validation.

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Sensor nodes are completely dependent on their battery lifetime; therefore, it is being constrained by a limited energy supply where the sensor nodes will not be able to execute sophisticated network protocols thus requiring a simple version of routing protocols.

In the static Wireless Sensor Network (WSN), Collection Tree Protocol (CTP) is regarded as one of the best data collection tree algorithms. However, this is not the case in Mobile Wireless Sensor Networks (MWSN) – where the sensor nodes move (and are not stationary) while sensing, collecting, processing, transmitting, and relaying the sensor data. The presence of the mobile nodes thus poses challenges to maintaining the network efficiency in MWSN.

An overview of MWSN and its routing protocols is discussed in Section 2. Section 2 also surveys the subject of mobility theories and simulation techniques. Section 3 provides details on the simulation settings and performance indicators. The corresponding Section 4 lists and discusses the simulation findings as well as the specific outcomes for each topology.

2. Literature Review

In the context of the Internet of Things and smart cities, the general services industry and the health sector have implemented wireless sensor networks. For all these reasons, researchers are emphasizing wireless sensor networks and addressing the challenges they encounter [1]. Energy usage and longer battery life are the two key issues in this type of network.

Sensor network environment requires information to be collected from the nodes in the network efficiently and reliably. This requirement has somehow brought challenges in collecting information, particularly in a dynamic wireless environment. The well-known energy constraints of sensor networks also require less communication among the nodes to achieve network efficiency. A dynamic wireless environment implements a multi-hop routing algorithm which requires its routing protocol to be able to adjust quickly to the changes in the network. An efficient routing algorithm is somehow required to cater to the needs of changing topologies in mobile wireless sensor networks.

2.1 Overview of Mobile Wireless Sensor Networks (MWSN)

A sensor node’s basic architecture [2] consists of 4 modules that are responsible for power, computation, and communications. Communications and processing use the most energy. The communication protocol stack must be carefully developed to overcome limitations on energy, longevity, traffic, and mobility.

Both stationary and moving nodes make up the MWSN. Sink nodes typically have greater power consumption, more robust communication capacities, and superior processing and storage of data capacities because they are primarily in charge of gathering data collected from adjacent node and transmitting it over to the host device [3]. The increased nodes’ mobility increases the wireless sensor network’s scalability and broadens the perceptual nodes’ area of coverage. The nature of MWSN is that it needs to repeatedly reconfigure its routes.

Since the position and separation of the nodes in the MWSN are random, probabilistic modelling is necessary to estimate and optimize the energy coverage [4]. Because the point of contact varies every time, maintaining connectivity while maintaining energy levels is a major challenge for MWSN. Here, the process of transferring data is crucial since it needs to be done effectively while utilizing the least amount of energy possible while maintaining connectivity.

Each node is powered by a battery which could be drained out in a matter of years or even weeks depending on the energy consumption by each sensor node’s application. This fact triggers the need for an efficient sensor node application to reduce power consumption as much as possible. The developer needs to assess the energy consumption of their developed application before their deployment in the field. Energy consumption must be evaluated in order to determine the network's lifespan and apply the necessary solution to these constraints.

The most typical scenario for a Wireless Sensor Network is that they stay there for the remainder of their lives. However, other applications call for mounting these nodes on marine buoys, within vehicles, or connected to other objects [5] whereas moving nodes may have distinct ways of mobility. Throughout the twenty-first-century technological revolution, new platforms [6] such as cloud services and the Internet of Things evolved. Implementing the CloudIoT methodology in the medical sector, according to experts, will greatly improve healthcare services and bring about several prospects for the industry.

Another common application of mobile wireless sensor networks is area monitoring; where it is deployed over a geographical location where some phenomenon is to be monitored, such as the use of sensors to monitor military crossings or the placement of natural gas or petroleum pipelines. In exploratory applications, MWSNs may be used to gather sensor node data from hard-to-reach, hazardous regions (such as undersea monitoring, wastewater tracking, and nuclear ecological surveillance [7]).

MWSNs are being applied to new uses and integrations, including in multiple-input multiple-output (MIMO) [8], machine-to-machine connectivity [9], as well as Industrial Internet of Things (IIoT) innovations that enable more intelligent control and decision-making [10].

Aside from what has already been stated, new application scenarios are emerging as a result of the advancement of in-vehicle communication technology, and wireless sensor networks with mobility will eventually constitute an essential component of the development of smart cities [11]. The use cases of Mobile Wireless Sensor Networks posed some challenging factors, mainly on computing power and network lifetime. Sensor nodes are strongly dependent on their battery lifetime and therefore are being constrained by the limited energy supply as well as the limited computing power. The sensor nodes will not be able to execute sophisticated network protocols and require a simple version of routing protocols. In a multi-hop wireless sensor network, the sensor nodes serve as both data transmitters and data routers. The event of power failure in multi-hop networks may cause a notable topological change and thus require the re-broadcasting of packets and re-organization of the network.

2.2 Routing Protocols in MWSN

According to their primary characteristics, routing protocols are typically split into four classes: hierarchical, data-driven, QoS-aware, and location-specific [12]. The referred classes are different in their roles during packet forwarding, on position knowledge, and differ in assumption with regards to the upper-layer applications. The hierarchical class routing protocols divide the network's traffic into clusters then elect the focal point for each cluster.

Naturally, sensor networks are deployed to collect information about the physical events by utilizing its nodes' sensors to reliably and efficiently collect information, and then relaying the sensor data to a central base station via multi-hop wireless communication. A protocol must be agile in order to execute routing with multiple hops in an ever-changing wireless environment – able to respond fast to network changes, while being efficient to minimize the amount of communication between sensor network nodes [13].

Several studies have been done previously concerning the evaluation of the routing protocols' performance in mobile wireless sensor networks (MWSN) focusing on different types of routing protocols, performance metrics, and parameters. A network model was developed to select the most efficient routing algorithm for a specific MWSN scenario, and five routing protocols; DSR, AOMD, AODV, OLSR, and DSDV [14] were used to achieve the highest attainable throughput and transmission fraction and the smallest feasible end-to-end delay and adjusted the distribution loads. These objectives were used in the study to discover a relationship between the performance indicators specified with various operation conditions.

An Ad hoc On-Demand Distance Vector (AODV) routing algorithm in MWSN was discussed thoroughly by Jambli *et al.,* [15] where an extensive simulation evaluated the loss of packets and usage of energy on mobile nodes at varying velocity, network concentration and route update interval (RUI). AODV is the protocol designed for mobile ad hoc networks, therefore it is not tailored for restricted resources circumstances (WSN) and is not energy aware. Simulation findings demonstrate a high proportion of packet loss and a decrease in mobile node overall network energy usage. This result thus reflects that the AODV routing protocol is unable to function equally in MWSN as it does in the static WSN. In a mobile context, AODV is unable to recognize fragmented routes and adapt to rapid topological shifts. An improvement is needed in the AODV protocol for it to be successfully implemented in a mobile environment.

2.3 Collection Tree Protocol Overview

The collection is the fundamental building component for sensor network applications. A tree topology formed at several points of collection is one of the most efficient ways to implement collection in a sensor network. As discussed by Gnawali *et al.,* [16] the element for other types of protocols is the tree topology itself. Collection Tree Protocol (CTP) is a sensor network distance vector routing protocol and data collection routing mechanism. It was known for its efficiency since it minimizes unnecessary communication between network nodes and is able to quickly adjust to network changes. Various studies with various performance metrics have shown that CTP is very efficient in the static environment of a Wireless Sensor Network (WSN), but not in the presence of mobile nodes as in a Mobile Wireless Sensor Network (MWSN).

Three logical software parts form CTP: the Routing Engine (RE), the Forwarding Engine (FE), and the Link Estimator (LE) [17].

i. Routing Engine (RE)
   The Routing Engine is in charge of beacon transmission as well as routing table construction and updates. A routing table is being updated on beacon reception at a fixed interval. It also consists of a metric that shows the quality of a link (known as ETX in CTP). The ETX value is exchanged between the nodes along with the beacons. The node will compare its neighbour based on the ETX value in parent selection, and it will select a node with the lowest ETX value as its parent.

ii. Forwarding Engine (FE)
   The Forwarding Engine oversees data packets forwarding either from the application layer or the neighbours, as shown in Figure 1 below [17]. It is also in control of discovering and rectifying routing loops and eliminating redundant packets.

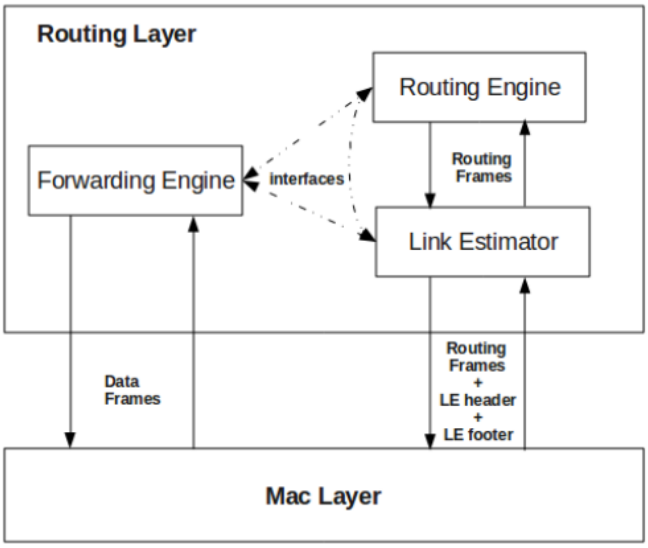

Fig. 1. Module interaction and message flow in CTP [17]

iii. Link Estimator (LE)
The Link Estimator determines the incoming and outbound link reliability for surrounding nodes of 1-hop communication links. The inbound indicator is calculated as a proportion of a neighbour's overall number of beacons transmitted divided by the fraction of collected beacons. The amount of transmission efforts taken by a node for it to transmit a data packet to its neighbour is calculated as the outbound metric.

To address the issues with resilience, dependability, and energy efficiency that the distance vector routing protocol faces in a highly dynamic wireless network, CTP employs three key strategies; Agile Link Estimation, Datapath Validation, and Adaptive Beaconing [16].

2.4 Methods and Selection of Simulation Tools

Several simulation techniques were examined for our study, including OMNeT++, NS-2, TOSSIM, Avrora, and Castalia. An extensible, modular, component-based OMNeT++ has extensive GUI support [18] where the simulation engine is included and prototypes can be readily incorporated into applications.

TOSSIM (also known as TinyOS Simulator) can properly capture every nuance of a mote's behaviours when used to simulate numerous motes at once [19]. TinyOS offers event-driven execution, which typically complements TOSSIM's event-based simulation.

AVRora is one of the commonly used simulation tools for Wireless Sensor Networks (WSN) developed by UCLA Compilers Group. In addition to its remarkable features of energy analysis, mobility extension model, and control flow graph construction, AVRora can achieve greater capacity and performance than TOSSIM by preventing synchronization of every node after every command [20].

NS2 (derived from the work Network Simulator) is the simulator name for a series of discrete event network simulators targeted at networking research, namely the ns-1, ns-2, and ns-3 [21].

Castalia is another simulator for Wireless Sensor Networks and lightweight embedded device networks in general. It is built on the OMNeT++ platform, and can be utilized for testing reasons of the distributed algorithms and protocols [22].

For this research, AVRora has been selected as our simulation tool mainly because of our familiarity with AVRora, apart from the fact that it is designed for sensor network applications simulation. AVRora offers scalability where it can run efficiently in handling multiple numbers of nodes. It also supports the energy mobility model and allows the network topology to be changed for testing the CTP in Mobile Wireless Sensor Network (MWSN) simulation.

2.5 Mobility Models

A research study carried out by Geng *et al.,* [23] stated that a mobility model is put forth to explain the way that mobile nodes move about how their pace and trajectory fluctuate throughout time. The two types of mobility models that are most prevalent in network analysis are traces and synthetic models.

Synthetic models are visionary models that use statistical approaches to depict each mobile node's relocation pattern to its destination. Traces models are known to be able to provide accurate information, especially in a long observation period. However, if the traces have not yet been created, new wireless sensor network environments are hay-wired to be demonstrated and this limitation will thus lead to the usage of synthetic models instead.

In this research, three different (synthetic) mobility models have been investigated:

i. Random Walk mobility model
The mobile nodes move arbitrarily and without restriction from one point to another. Additionally determined at random and without regard to any other nodes in the network are the destination, speed, and direction. The entities in the random walk model are extremely unpredictable since a mobile node moves from one point to another by picking its path and velocity. Both the newly selected speed and trajectory are chosen from predefined ranges [24]. Because the node's current movement is devoid of its previous trajectory and speed, this model is also known as a memory-less mobility model.

ii. Random Waypoint mobility model
The most extensively used for mobile ad-hoc networks because of its simplicity [23]. Each mobile node in this mobility model chooses an arbitrary location inside the simulation zone and a speed that has an even distribution between [V_{min}, V_{max}]. When the mobile node arrives at its intended location, it stops for the length specified by the pause interval parameter. Following this time, the mobile node selects another arbitrary location in the simulation zone and travels towards it. This procedure continues until the simulation is completed.

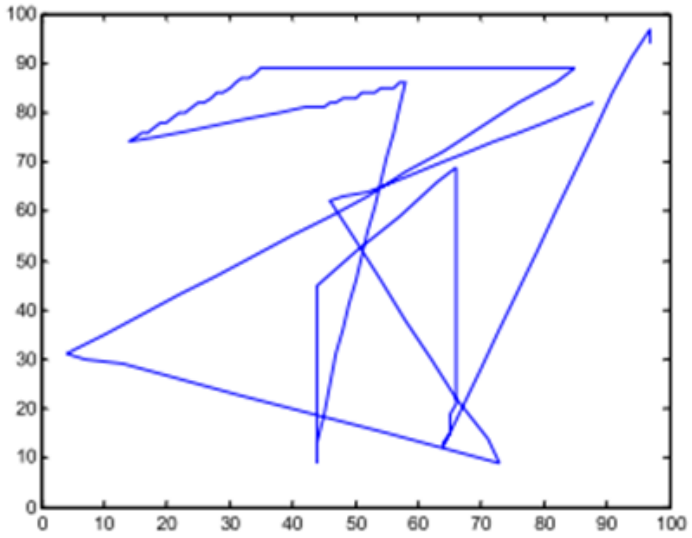

Fig. 2. Movement pattern using Random Waypoint on a 100m x 100m simulation area [23]

iii. Gauss-Markov mobility model
This approach employs chronological dependency, in which the velocity and trajectory of a mobile terminal are updated by examining the values of previous time intervals. The rate of randomness employed in the estimation of both values can be changed depending on the properties of the simulated wireless network [25]. Gauss-Markov mobility model retains the memory of prior behaviours.

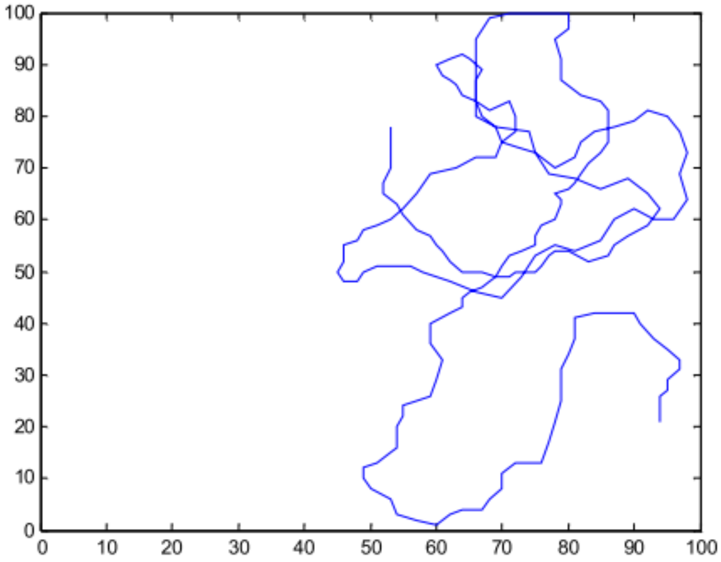

Fig. 3. Movement pattern using Gauss-Markov on a 100m x 100m simulation area [23]

Because of its simplicity thereof, the Random Waypoint mobility model was utilized in this work, and it is the sole mobility model currently supported by AVRora simulator. The Random Waypoint mobility model is believed to be sufficient for our research project simulation purposes.

A few research studies have been conducted to assess the efficiency of the Collection Tree Protocol in static or mobile environments. However, most of the research projects either use different performance metrics or concentrate on different routing algorithms in their studies, apart from the evaluation on CTP performance on average packet loss percentage and total energy consumption in MWSN.

This paper's key contribution is as follows;

i. Investigation of the implications of mobile nodes on Collection Tree Protocol (CTP) performance through extensive simulation using the selected simulation tools.
ii. Identification of the impacts of a varying number of mobile nodes, mobile node velocity, and network density on average packet loss and energy consumption in the network.
iii. Evaluation of the overall performance of Collection Tree Protocol (CTP) in Mobile Wireless Sensor Networks (MWSN) in terms of packet loss percentage and total energy usage.

3. Methodology

This performance study will commence with the identification of the performance indicators that will be utilised to assess the efficiency of CTP in MWSN. The identification of tools and simulation setup will then proceed thereafter, followed by the parameters setting on the simulator. After the setting is done, simulations of the CTP application will be run in varying network topologies followed by the collection of results and thus documentation of the findings. The final stage of this research is to assess the efficiency of CTP in Mobile Wireless Sensor Networks (MWSN)

3.1 Performance Metrics

One of the ways to evaluate the energy usage and reliability of data transmission and relaying is by adopting modelling and simulating the experiments on the simulation tools. Simulating the experiments may provide flexibility to the tester in evaluating complex scenarios without being interfered with any actual environment's constraints.

To evaluate the capability of Collection Tree Protocol (CTP) routing protocol in Mobile Wireless Sensor Networks, this project concentrated on two performance measures, which are as follows:

i. Average packet loss
The definition of the average packet loss is the percentage of packets delivered by the originating node that are lost or discarded before reaching the sink (base station). The average percentage of packet loss is calculated by dividing the overall number of packets transmitted by any given node, N_S, by the average ratio of packets incorrectly transmitted (dropped or loss) to the sink (base station), N_L.

$$\text{The average packet loss (\%)} = \frac{N_L}{N_s} \times 100$$

ii. Average total use of energy
The average overall use of energy is defined as the average sum of energy utilized by network nodes via radio transmission and processing. The overall network energy spent, denoted as P_E , can be determined by accumulating all of the energy used by each node throughout the simulation period for transmission (T_X), reception (R_X) and processing. The

formula used to calculate the sum of energy utilized by all of the nodes while transferring association and data packets is shown below.

$$\text{Average total energy consumption} = \sum_{i=1}^{n} \square \left(E_{Tx}^{i} + E_{Rx}^{i}\right)$$

3.2 Tools and Simulation Setup

AVRora has been considered as the best simulation tool for this study as compared to others because it can simulate a mobile environment and is capable of linking the TinyOS codes into hardware implementation. AVRora can also provide an outstanding simulation of the real algorithm running on a MICA2 or MICAZ platform.

TinyOS needs to be installed on the testing machine's platform. TinyOS is one of the embedded operating systems for wireless sensor networks. Cygwin needs to be installed as well since this research project is hosted on a Windows platform. Cygwin is the Linux-like environment for the Windows platform. Table 1 below summarized the environment setting for this research:

Table 1
General simulation setting

Operating System	TinyOS2.X (on Cygwin)
Simulation Software	AVRora-beta-1.7.115
Application	MultihopOscilloscope
Routing Protocol	Collection Tree Protocol (CTP)

Once the installation for Cygwin is done, the next step is to install the native compilers that are required to run the AVRora simulator. The native compilers that are required are listed below:

i. Atmel AVR Tools: avr-binutils, avr-gcc, avr-libc, avarice, avr-gdb, avrdude
ii. MSP430 Tools: base, python tools, binutils, gcc, libc

After the native compiler's installation, the TinyOS toolchain and source tree are to be installed next. Then the final step is to configure the system environment variables accordingly.

This project simulates the MultihopOscilloscope application; a simple application using the MultiHop routing protocol. A node that has the MultihopOscilloscope function deployed will sample its initial sensor on a regular basis and transmit a message for every few measurements. Data collected from several nodes in the ad-hoc network are subsequently obtained by the base station (sink node). The MultihopOscilloscope application consists of a Tree Routing Engine, which is responsible for computing the routes for collection apart from enabling the node to find the path with the least number of transmissions to any one root. The Tree Routing Engine builds a set of trees rooted at specific nodes (roots) and maintains these trees using the information (on the quality of one-hop links) provided by the link estimator.

Each node (root) is part of only one tree at any given time and the node does not bother which tree it is part of. A message is sent towards a root, but which one is being sent is not specified. The tree is proactively maintained by periodic beacons sent by each node, and all nodes maintain the same average beacon sending rate. The contents of the beacon are the node's parent, current hop count, and cumulative quality metric.

3.3 Mobility Models and Network Topology

This project is applying the Random Waypoint Mobility Model (RWP) for the node's movement, where a mobile node will start its move by staying in one location for a certain period. Once the time expires, the mobile node then chooses a random destination in the simulation area (of 100 x 100 for this research project), with a consistently distributed velocity across the range (min-speed, max-speed). The mobile node subsequently proceeds at the designated velocity towards the next selected destination. When a mobile node arrives, it stops for a predetermined amount of time before restarting the operation [23]. As compared to other mobility models, Random Waypoint Mobility Model is the most commonly used model, because of its simplicity and applicability for many scenarios, apart from the fact that it is already implemented in the AVRora simulator.

The simulation experiments will be performed using a CTP implementation in AVRora Beta 1.7.114 with 25 nodes spread in a rectangular simulation area of 100m x 100m. The network will include a fixed base sink at position (45,45) meters, as depicted in Figure 4 below:

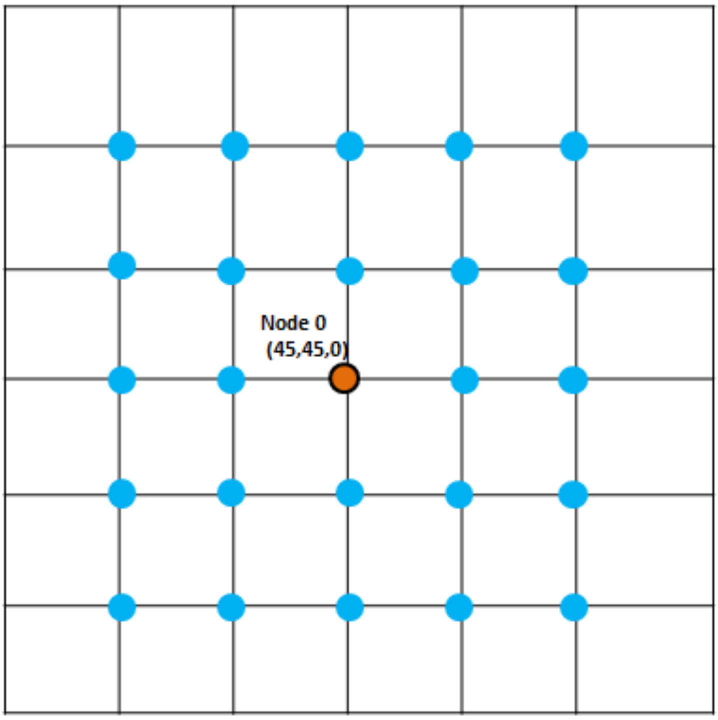

Fig. 4. Nodes topology setup in 100m x 100m simulation area

There are five different topologies setup for this project's simulation purposes:

i. Topology 1 setup is to study CTP performance in the static network, depicted in Table 2.

Table 2
Topology 1 simulation setting

Simulation Tool	AVRora-Beta 1.7.114
Simulation Duration	200/ 400/ 600/ 800/ 1000 seconds
Platform	Micaz
Application	MultihopOscilloscope
Routing Protocol	CTP
Simulation Area	100 m x 100 m
Number of Nodes	25 nodes (ALL static nodes)
Seedings	98989, 43434, 67676, 79797, 89898

ii. Topology 2 setup is to study CTP performance in relation to the quantity of mobile nodes, depicted in Table 3.

Table 3
Topology 2 parameters setting

Simulation Tool	AVRora-Beta 1.7.114
Simulation Duration	1000 seconds
Platform	Micaz
Application	MultihopeOscilloscope
Routing Protocol	CTP
Simulation Area	100 m x 100 m
Number of Nodes	25 nodes (Both static and mobile nodes)
Number of Mobile Nodes	4/ 8/ 12/ 16/ 20/ 24
Mobility Model	Random Waypoint
Pause Time	0.5 second
Min-Max Speed	9-10 m/s
Seedings	98989, 43434, 67676, 79797, 89898

iii. Topology 3 setup is to study CTP performance relative to the velocity of mobile nodes, depicted in Table 4.

Table 4
Topology 3 parameters setting

Simulation Tool	AVRora-Beta 1.7.114
Platform	Micaz
Application	MultihopOscilloscope
Routing Protocol	CTP
Simulation Duration	1000 seconds
Simulation Area	100 m x 100 m
Number of Nodes	25 nodes (Both static and mobile nodes)
Number of Mobile Nodes	4/ 8/ 12/ 16/ 20/ 24
Mobility Model	Random Waypoint
Pause Time	0.5 second
Min-Max Speed	4-5/ 9-10/ 14-15/ 19-20/ 24-25/ 29-30 m/s
Seedings	98989, 43434, 67676, 79797, 89898

iv. Topology 4 setup is to study CTP performance relative to the density of static WSN, depicted in Table 5.

Table 5
Topology 4 parameters setting

Simulation Tool	AVRora-Beta 1.7.114
Platform	Micaz
Application	MultihopOscilloscope
Routing Protocol	CTP
Simulation Duration	1000 seconds
Simulation Area	100 m x 100 m
Number of Nodes	5/ 10/ 15/ 20/ 25 nodes (ALL static nodes)
Seedings	98989, 43434, 67676, 79797, 89898

v. Topology 5 setup is to study CTP performance relative to the density of MWSN, depicted in Table 6.

Table 6
Topology 5 parameters setting

Simulation Tool	AVRora-Beta 1.7.114
Platform	Micaz
Application	MultihopOscilloscope
Routing Protocol	CTP
Simulation Duration	1000 seconds
Simulation Area	100 m x 100 m
Number of Nodes	5/ 10/ 15/ 20/ 25
Number of Mobile Nodes	All nodes
Mobility Model	Random Waypoint
Pause Time	0.5 second
Min-Max Speed	9-10 m/s
Seedings	98989, 43434, 67676, 79797, 89898

The Random Waypoint (RWP) had been selected as our mobility model because it is the most common and widely used. Additionally, RWP is the only mobility model that is currently being supported by the AVRora simulator that is used. Due to the short duration of completing this research project, the existing mobility model supported by the simulator has been decided to be proceeded with.

4. Results and Discussions

Each simulation was run within a simulation area of 100 metres x 100 metres, with a gap of fifteen metres separating each node. The statistical analysis for each experiment is carried out utilizing the Excel Statistical Analysis Tool. The detailed results of each topology are discussed in the next subsection.

4.1 Effect of Simulation Time (Duration) on Static Wireless Sensor Networks (WSN)

Based on the statistical evaluation shown in Figure 5 below, the highest average packet loss was recorded during the shortest simulation period of 100 seconds, with an average of 63% packet loss. At 200 and 300 seconds, the average percentage loss decreased to 61% and then to 60% at 400 seconds. The average packet loss remains constant from 500 seconds to 1000 seconds with a 60% average packet loss.

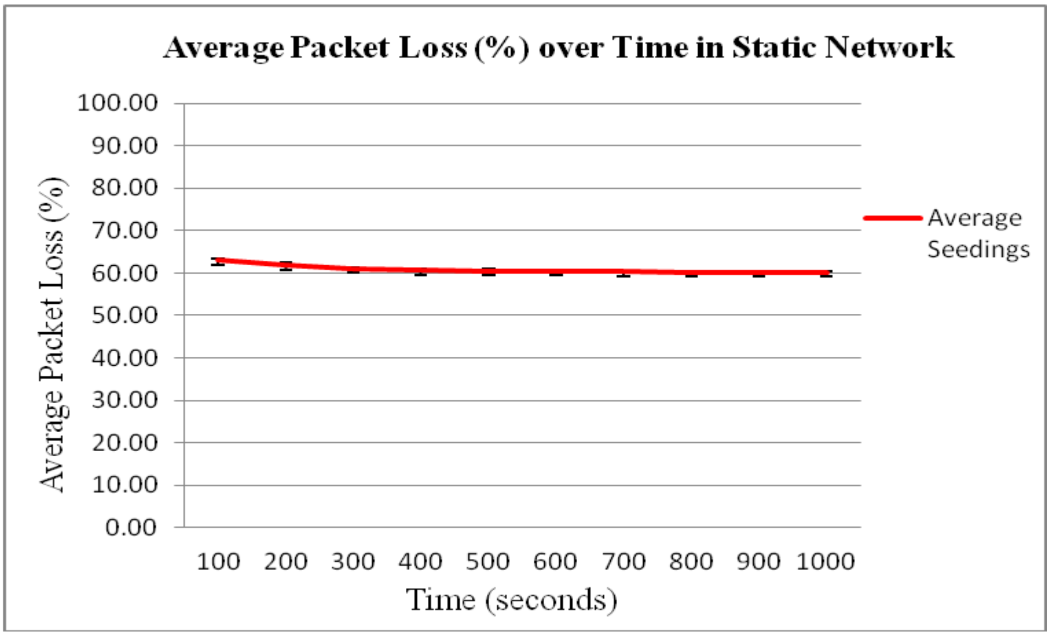

Fig. 5. Average Packet Loss (%) over Time in Static Network

As from the statistical analysis in Figure 6 below, the lowest average total energy consumption was recorded during the shortest simulation period of 100 seconds, with an average of 10000 Joule. The energy consumption was then increased gradually with the increase of the simulation period; with the highest energy consumption recorded within the period of 1000 seconds.

In WSN, all 24 nodes in the simulation area are static, which explained the constant values in the average packet loss plotted on the graph. However, the average overall energy use in Figure 6 further entails that the average total energy consumption is increasing over time in WSN. The longer the network lifetime, the more energy will be consumed by each of the nodes for transmission.

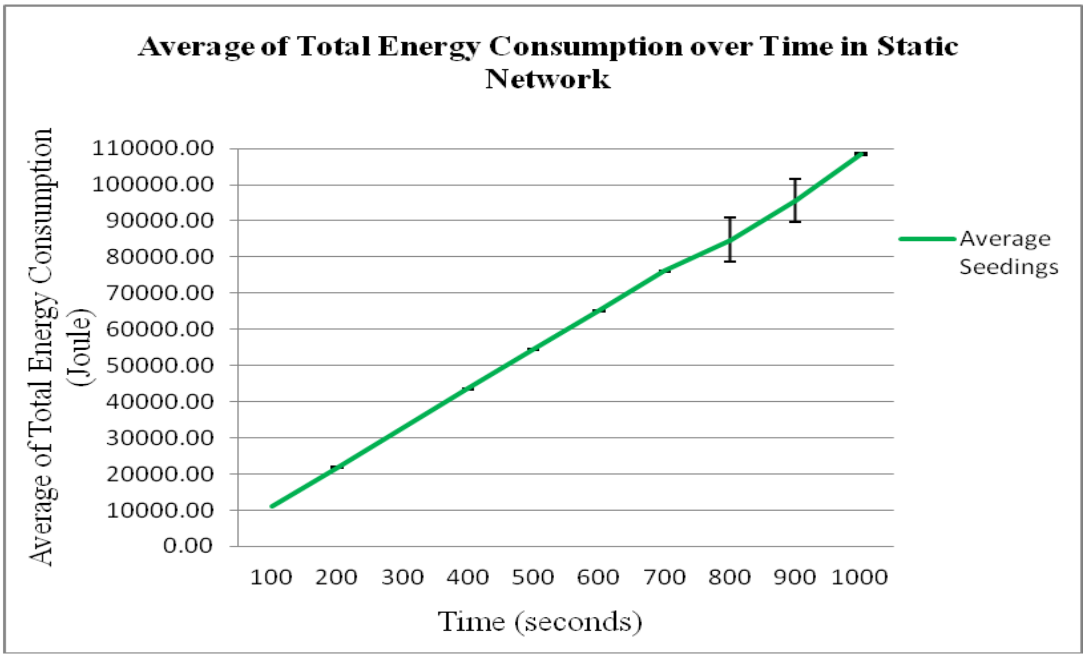

Fig. 6. Average of Total Energy Consumption over Time in Static WSN

4.2 CTP Performance over Time in Mobile Wireless Sensor Network (MWSN)

The objective of Topology 2 was to observe the percentage of packet loss in 25 nodes of mobile wireless sensor networks. The main difference between Topology 1 and Topology 2 is the existence of mobile nodes in Topology 2. The percentage of packet loss was observed in varying numbers of mobile nodes; with the assumption that not all the nodes in the network are mobile (some of the nodes remain static).

Based on the analysis in Figure 7, the average packet loss in MWSN is higher than the static WSN. From the simulation results, it can be summarized that the percentage of packet loss is increasing with the number of mobile nodes in the network.

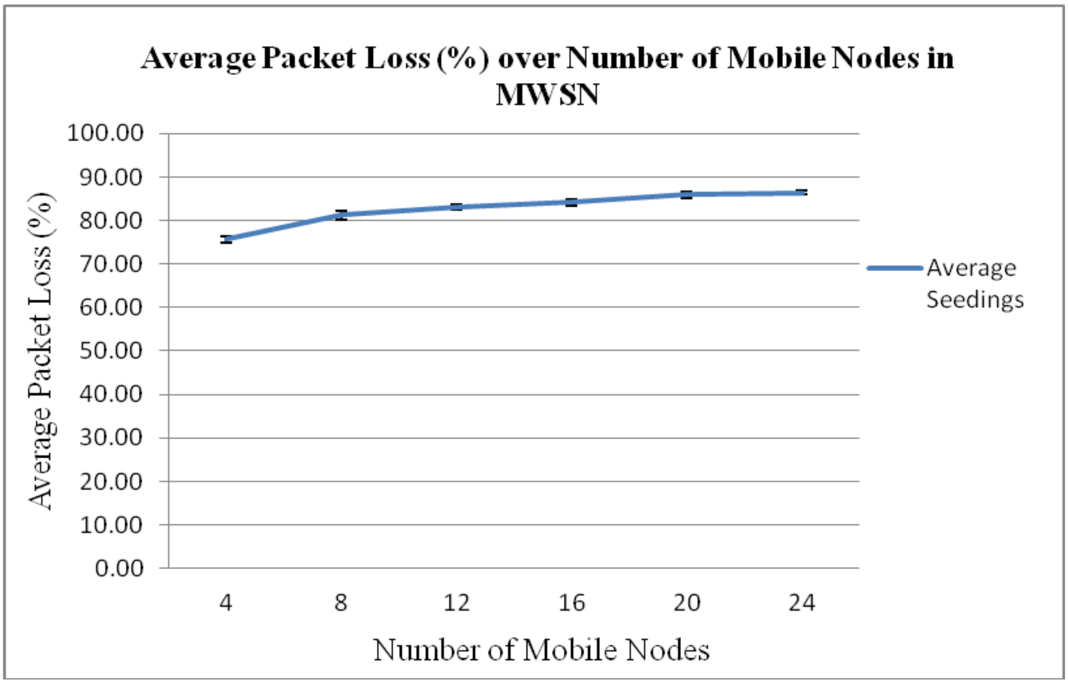

Fig. 7. Average Packet Loss (%) over the Number of Mobile Nodes in MWSN

As the percentage of packet loss grows, so does the average overall energy usage, as seen in Figure 8 below.

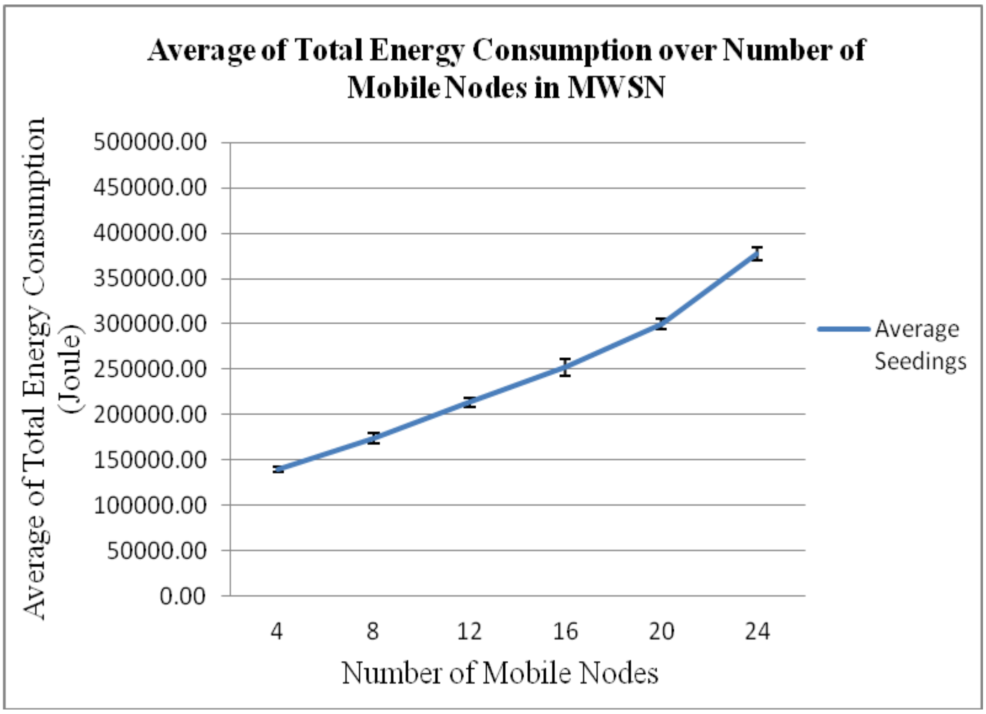

Fig. 8. Average of Total Energy Consumption over the Number of Mobile Nodes in MWSN

Packet loss or packet dropped may occur when data is traveling across several intermediary nodes to reach its destination (base sink). Packet loss can be maintained by the CTP's efficient routing path mechanism and link estimator. The high energy consumption recorded in the simulation results may be due to the effort needed by the CTP's Forwarding Engine in detecting and repairing routing loops as well as suppressing duplicate packets, as well as by the CTP's Link Estimator in assessing both the inbound and outbound link reliability of the neighbouring nodes.

4.3 CTP Performance Over the Mobile Node Velocity

The objective of Topology 3 was to observe the implications of node mobility (with varying velocities) on average packet loss percentage and overall energy use. The statistical analysis in Figure 9 and Figure 10 depicts the average packet loss and energy use of the mobile nodes with six velocity ranges.

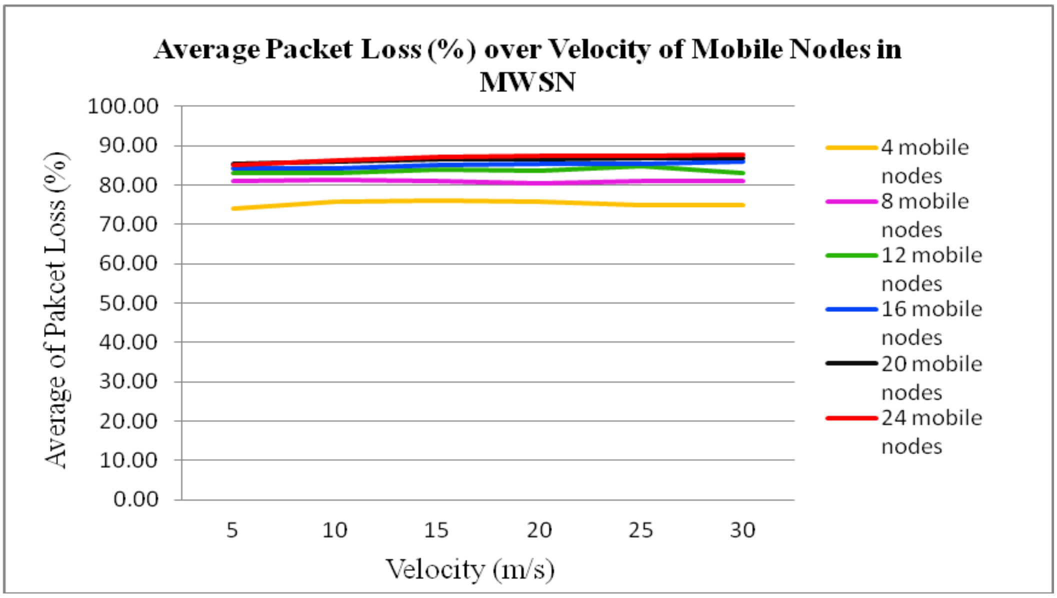

Fig. 9. Average Packet Loss (%) over Velocity of Mobile Nodes in MWSN

Based on Figure 9 and Figure 10, an increase in the velocity of mobile nodes has only minimal effects on network overall performance with respect to of average packet loss and total usage of energy. For every 5 m/s increase in velocity, packet loss rises by 0.5% on average. This indicates that CTP routing still maintained the packets even when the mobility increased, where higher or lower speed does not significantly contribute to the average packet loss and total usage of energy. Apart from that, the zigzag node movement on Random Waypoint (RWP) mobility model that we have selected for this research project can also be related to the simulation results for Topology 3. The varying velocities of mobile nodes did not have a significant impact on both the average packet loss and total usage of energy.

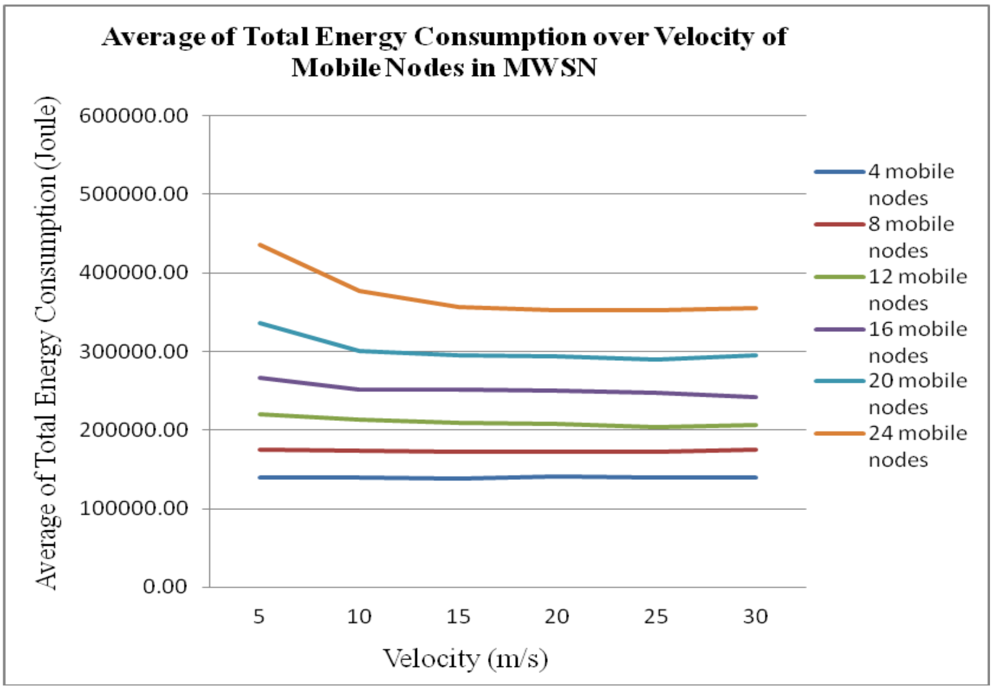

Fig. 10. Total Energy Usage over Velocity of Mobile Nodes in MWSN

4.4 CTP Performance Over the Density of the Network in WSN and MWSN

The analysis result depicted in Figure 11 shows that the average packet loss increases as the number of nodes in the simulation area increase in the static network of WSN. Figure 11 also depicts the inverse relationship between average packet loss in the MWSN (assuming that all nodes, excluding the static base sink, are mobile), where the average percentage of packet loss decrease as the number of nodes in the simulation area increase.

In the MWSN, the smallest number of nodes in the simulation area recorded the highest number of percentage packet loss mainly because of the movement of the nodes, the random distribution of the nodes that leads the nodes to be completely isolated from each other. These situations thus caused the packets forwarded were not able to reach the base sink.

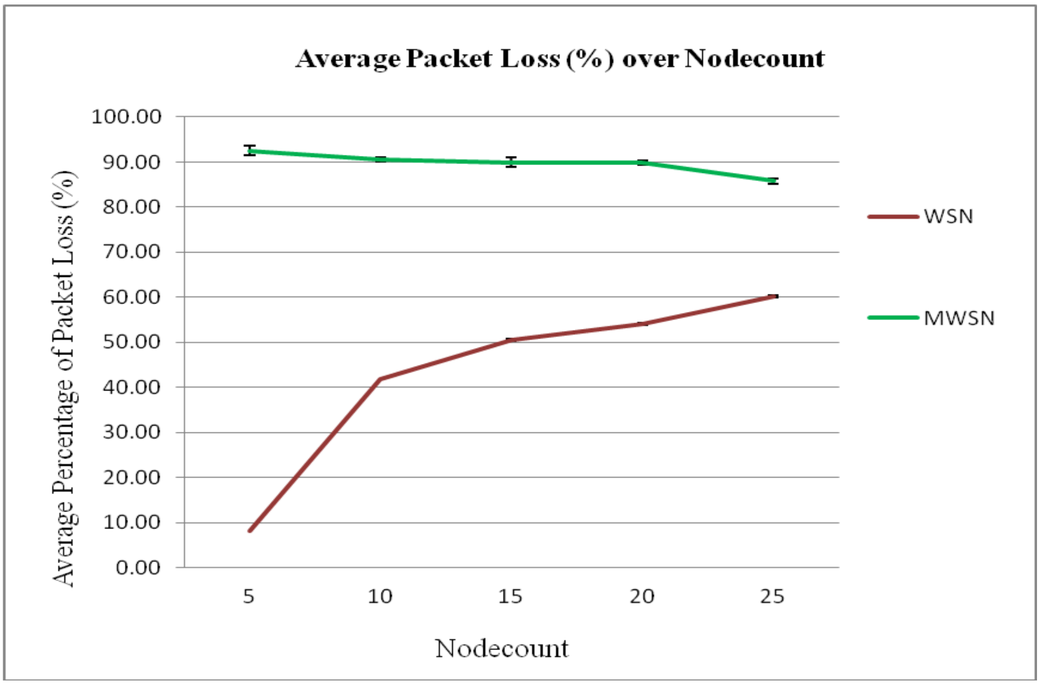

Fig. 11. Average Packet Loss (%) over Nodecount in WSN and MWSN

As for the average total energy consumption depicted in Figure 12, the increase in node count reflects a gradual increase in average total energy consumption in MWSN. As compared to static nodes, mobile nodes in CTP applications significantly require much energy for their random movement, and for their effort in detecting and repairing routing loops as well as determining the link quality of the neighbouring nodes.

Packet loss occurs when data is traveling across several nodes to reach the base sink. Packet loss in this case is caused by network congestion, where a higher number of nodes in the network indicates more packet forwarding to be done between the intermediary nodes before the packet can reach the base sink. A higher number of packets dropped may also indicate a higher number of packets retransmission/forwarding to be done, thus leading to a higher number of energies consumed by each node in the network for retransmission.

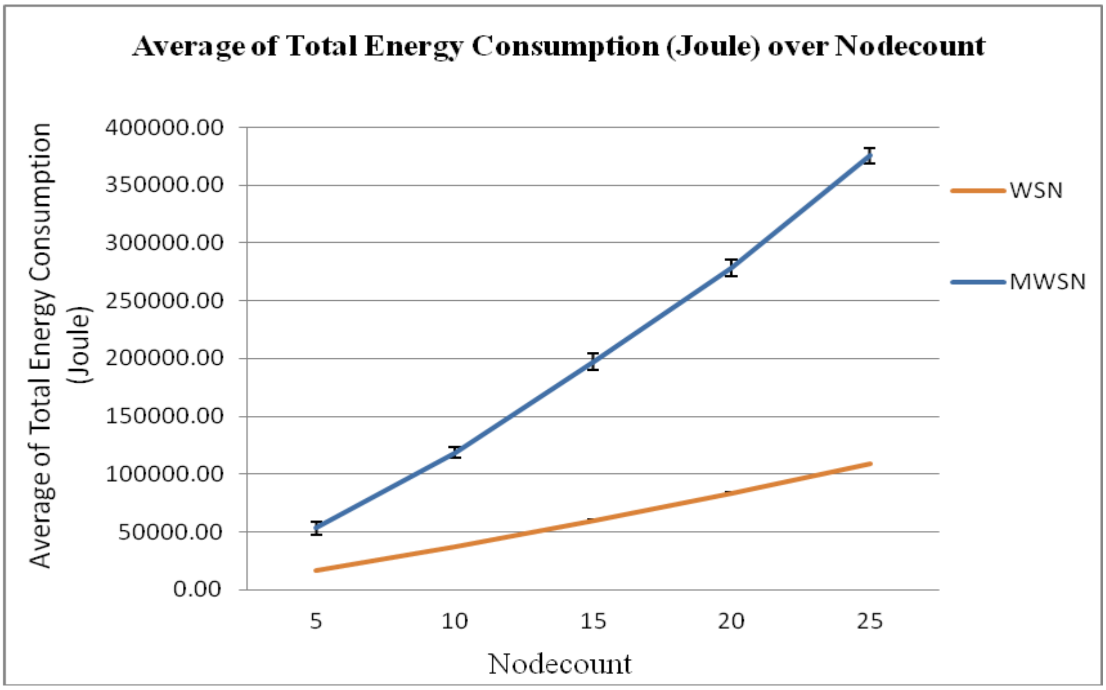

Fig. 12. Average of Total Energy Consumption (in Joule) over Nodecount in WSN and MWSN

Due to the network's energy limitations, it is important to employ an effective routing strategy that involves choosing a route with less energy consumption.

In MWSN setups, CTP is not recommended due to greater packet loss rates. As the number of mobile nodes increases, it also raises the percentage of packet loss in the network. The average amount of overall energy utilized increased as a result of this.

In the dynamic circumstances of WSNs, energy consumption and prolonged battery life are the main concerns. For instance, in the application of tracking the water quality of a particular part of the ocean, this is one of the underwater MWSNs that uses active mobility. Sensor nodes may have propellers attached to them, and they move intentionally from one location to another. The battery life limits the sensor nodes, as they solely depend on it for power. Therefore, a lightweight routing protocol that is simple to deploy is crucial for the sensor nodes due to their limited resources. This is to ensure efficient communication and minimize power consumption.

5. Conclusions

Based on the simulation results, it can be concluded that in the static wireless sensor network, the longer the network lifetime, the more energy will be consumed by each of the nodes for packet transmission and forwarding. Due to the energy constraint in the network, it is somehow vital to implement an efficient routing decision that includes the selection of a path with less energy consumption. Through simulation that has been done on Topology 1, it is sufficient to say that the application of CTP in WSN is efficient due to the constant percentage of packet loss recorded during a longer transmission period. It is also sufficient to say that in a static WSN, the CTP's optimum routing path mechanism and link estimator maintains the packet loss. The high energy consumption recorded in the simulation results may seem justifiable by the effort of the Forwarding Engine of CTP recognises and resolves routing loops whilst eliminating redundant transmissions, and the CTP's Link Estimator's effort in evaluating the incoming and outbound route reliability surrounding nodes.

However, in the MWSN, the percentage of packet loss is higher than in the static WSN. The percentage of packet loss is increasing with the number of mobile nodes in the network. The increase in the average of packet loss also increases total energy use on average. An increase to mobile node velocity has only incurs minor impacts on the overall performance of the network when considering of average packet loss and average total use of energy. This shows that CTP routing still maintained the packets even when the mobility increased, where higher or lower speed does not significantly contribute to the average of packet loss and total use of energy. The mobility model that has been selected also has a significant impact on the overall network performance – the waypoints are uniformly distributed over the simulation area, where the movement pattern of each node is along a zigzag line from one waypoint to the next.

One limitation of the research is that tests conducted with simulators may not precisely replicate the real-world circumstances of the MWSN they are imitating. This might result in differences between the outcomes of simulations and real-world events. Several factors can contribute to discrepancies between underwater MWSN experiments carried out in a simulator and those carried out in an actual underwater environment. Simulators may not precisely replicate the hydrodynamic effects, such as current, turbulence, and wave action, that exist in actual underwater environments. These effects can significantly impact the behaviour of sensor nodes and aquatic species. Certain sensors may exhibit behaviour or constraints that are challenging to precisely replicate in simulations. It can be tricky to duplicate certain characteristics of sensors in a simulated environment, which might include non-linear responses, drift, or sensitivity to external influences.

A few prospective, relevant future works have been identified for this study. In subsequent research, we will deploy CTP, for instance, in the actual underwater environment of MWSN. This future deployment may help to validate the results that have been obtained from the simulation approach. The interaction between the behaviour of the sensor nodes running the CTP algorithm and its environment is crucial to better understanding CTP's behaviour and performance in MWSN. Apart from that, in the future, we should enhance the forwarding techniques and reduce the energy consumption of the CTP algorithm to improve its overall performance in MWSN.

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