Performance Analysis of Burst Traffic Awareness Based Mobile Sink Routing Technique for Wireless Sensor Networks

Sercan YALCIN* ⒾⒹ , Ebubekir ERDEM ⒾⒹ

Firat University, Department of Computer Engineeering, Elazig,23119, Turkey

Highlights
• This paper proposes two algorithms to detect mobile sink paths.
• The algorithms consider the burst data traffic in the network.
• The proposed methodology maximizes the network lifetime.
• The burst traffic situations on network efficiency is also analyzed.

Abstract

In wireless sensor networks (WSNs), it is vital to adopt a suitable mobile routing algorithm between sensor nodes and mobile sinks (MSs) for data gathering efficiently. In WSNs, random mobility of the MSs increases the mobile path length in the network when data traffic bursts. Therefore, the focus of this study is to overcome burst traffic in an energy-efficient way using the MSs in the network. In this study, a new burst traffic awareness adaptive mobile routing scheme based on heterogeneous WSNs has been developed. The network area is divided into two cluster groups in the proposed scheme, each with a certain number of clusters. In the network, a MS of each cluster group acts. The MSs gather all data in a single-hop attitude as soon as they arrive at the clusters. In this way, the energy load is distributed evenly among the network. Once a burst data is detected in the routing model, a MS updates its trajectory to the cluster head (CH) where the burst occurs. The performance results validate that the proposed methodology outperforms recent studies based on the network lifetime, average energy consumption, and average mobile path length. Also, the effect of the burst traffic situations on network efficiency is analyzed with simulation.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) compose many distributed and low-cost sensor nodes that communicate with one another to serve in real environments [1,2]. Many applications such as smart grid, health operations, precision agriculture, industrial and urban land tracking, target location of the battlefield, physiological data collection, and smart transportation system [3] can be presented as the WSN applications [4]. In WSN, the primary function of each of the distributed sensor nodes is to transmit the data perceived in the environment to other sensors or to deliver them to the receiver (sink) node [5]. A sink node is a fixed position node or a mobile node [6], capable of connecting the WSN to a known communication structure. In traditional WSNs, data collection between sensor nodes and a central sink is based on single-hop or multi-hop communication. However, data collection methods are faced with energy and load balancing limitations [7,8]. In the case of static sinks, the nodes next to the sinks consume the existing energy faster due to the intersection of multi-hop paths and more data traffic towards the sink. This problem is called hot spot (hole) problem [9]. However, a mobile sink (MS) may provide energy load balancing and adaptive energy depletion in the WSN thanks to the movement on certain paths [10].

The roaming (mobility) types of the sensor nodes are known as controlled and uncontrolled roaming. In uncontrolled roaming, sensor nodes are free to visit randomly in the network field, but in controlled roaming, they have to follow the predefined path throughout the network lifetime. The controlled roaming

*Corresponding author, e-mail: svancin@firat.edu.tr

is also divided into two types. The first is that the MS can discover the adaptive roaming route by tracking the node's fixed sojourn throughout the network life. This type of controlled roaming is called inflexible roaming. Second, fixed temporal locations are chosen for the MSs in each round to maximize network life. This controlled roaming is known as an adaptive, robust, and flexible mobility type [11-13]. WSNs are divided into homogeneous and heterogeneous networks according to the sensor node features they contain. The networks with homogeneous nodes contain the nodes with equal energy features, whereas heterogeneous structured networks are the opposite. It is relatively advantageous to create heterogeneous WSNs in terms of the diversity of the nodes in the network and the energy consumption in different amounts and time. That provides to ensure the energy and load balance of the network.

Although a MS provides significant advantages to the WSN, it is faced with data communication and management problems in its routing mechanisms [14]. Therefore, the routing protocols need to be adapted to deal with the mobility in the WSNs. Depending on the routing structure, they are classified as hierarchical, flat and location-based routing protocols [15]. Contrast to other types of routing, hierarchically based routing protocols provide better performance in terms of energy, scalability, and extending the lifespan of the mobile WSNs [11]. Most of the current data acquisition methods use a hierarchically based routing mechanism, such as the clustering method that generates non-overlapping clusters with a cluster head (CH) in WSNs [16]. However, it is critical to model an efficient data gathering between sensor nodes and MSs and design realistic heterogeneous WSNs by efficiently selecting different mobility patterns.

In this direction, a mobility model based on burst traffic awareness has been developed with two MSs in order to collect energy-conserving data with the methods proposed in this study. With this mobility model, many issues such as balancing the energy load and determining the mobile path length are addressed in heterogeneous WSNs. In this study, an adaptive and controlled roaming technique is proposed.

The remaining sections of this paper have been organized as follows; Section 2 provides a survey about related works. Section 3 includes the detailed presentation of the proposed method. The performance analysis and simulation results are presented in Section 4. Finally, Section 5 draws the conclusion by mentioning future studies.

2. RELATED WORKS

Although there are many studies related to this study in the literature, we present more relevant and recent studies in the WSNs as follows.

Zhang and Wan [17] proposed the Dynamic Path Planning for Mobile Sink with Burst Traffic (DPPMSBT). The algorithm aims to balance the energy and node load in WSN and prevent traffic bottlenecks. This algorithm considers grid segments of the network, premise tracing, traffic density awareness and prediction, resources collaboration strategy, and dynamic routing arrangement.

Naghibi and Barati [18] presented a geographic routing plan with a mobile sink (EGRPM) to set the sensor network as a geographic zone. The nodes in areas called cells in these regions sense the data in the environment and use two MS nodes to collect this data. The communication between nodes and MS node occurs in two classes in the cell, single tabbed communication cells (SCCs) and multi-tabbed communication cells (Multi-CCs). Within these two classes, the MS nodes collect all data and transmit it to the main center. Although the network life and packet delivery rate are increased significantly and these proposed methods decrease energy consumption, risky scenarios such as traffic density and packet collision have not been taken into account in their study.

Toor and Jain [12] presented a scheme named mobile energy aware cluster based multi-hop (MEACBM) using MS nodes in 3-level heterogeneous WSNs to improve the lifetime of the sensor network. With this scheme, CHs are selected from the highest energy nodes. The CHs collect data from cluster members. After that, the network area is divided into sectors. There is a MS node for each sector. The MSs collect the data from the CHs through the Expectation-Maximization (EM) algorithm and deliver it to the BS. On the other hand, in the proposed scheme, the sensor nodes in clusters have poor scalability and the speed of the MS

node is not adaptively assigned. Therefore, the energy balance in the network could not be achieved sufficiently.

Yalçın and Erdem [19] proposed two algorithms for heterogeneous mobile networks, based on bacteria interaction, with a new CH selection and routing algorithm. The CH selection was made based on the interaction function value, degree of an energy node, and distance to neighbor nodes.

Ahmad et al. [20] proposed a data transmission method in WSNs. In the method, the nodes go through three stages: selection of the primary node, formation of the group-based region, and MS trajectory-based data transmission, which enables the data collection from leaf nodes. However, this method increases the latency to compute the primary sensor node and then the agent sensor node.

Alsaafin et al. [21] presented a routing method that constructs the mobile paths to reduce energy depletion and latency caused by the MS node in the WSN. This algorithm operates in four main stages: data detection, meeting point selection, trajectory design, and data transmission: Due to the use of a single MS, data collection is not prioritized, and packet loss occurs due to buffer overflow. The energy efficiency of the MS is also not taken into account in the network.

Wang et al. [22] presented the clustered dynamic route's adjustment approach (EECDRA). This approach provides adaptive path maintenance according to the current position of the MS with minimum route reconstruction cost of the nodes. This approach improves the network lifetime due to the use of optimum routes and the number of CHs. The MS moves only if the displacement condition is met, so it takes a long time to achieve the displacement condition.

Alhasanat et al. [23] proposed a link-based method in which sensor nodes are divided into multiple clusters depending on the connectivity of the entire group of nodes in a single cluster. The network data is collected with a path-constrained MS. This method uses a single MS and therefore has not produced a perfect solution to a buffer overflow and data latency problem.

Shi et al. [5] proposed the energy management algorithm to improve the energy consumption between sensor nodes by controlling the workload between MSs and the movement of MSs. Although this algorithm consumes energy efficiently in the network, it creates high end-to-end latency between the nodes.

Salarian et al. [24] presented an energy-saving MS path selection strategy for WSNs. In this study, weighted rendezvous planning (WRP) method was used to select the appropriate sensor nodes as meeting points. Although this method reduced the number of multi-hop transmissions, it created high overhead as the algorithm had to recalculate the weight of other nodes.

Zhu et al. [25] presented a tree cluster-based data collection algorithm for industrial WSNs with MS. This algorithm uses the new weight-based tree construction method where root nodes are considered meeting points. This method can significantly balance the load of the whole network, reduce energy consumption, alleviate the hotspot problem, and extend the life of the network.

Tang et al. [26] presented a clustering method dependent on minimum path planning with a MS. This method determines the maximum number of multi-hop communications in the network as the primary measure for designing CHs in the network. However, this method may not be implemented on the large-scale networks where it is not possible to take information related to the position and condition of the nodes.

Dash [27] proposed an algorithm to avoid sensor buffer overflow using MSs in WSNs. In this algorithm, data collection is performed by a MS in a predefined route. The author of this study also provided a recovery method for potential MS failures in the network. However, the study limits the route planning of the MS.

Vancin and Erdem [28] proposed an energy-efficient clustering algorithm for WSNs. In this study, the authors formulated the threshold value as a balanced and sampled value when the CH selection is made within the cluster. This algorithm performed better than other DEEC-derived methods in terms of the energy

efficiency. However, the lack of network modeling details and data gathering problems indicate the deficiencies of the study.

3. THE PROPOSED METHOD

In this study, two MSs are used in the network. The MS-1 and MS-2 are responsible for cluster groups 1 and 2, respectively. Burst traffic is created by increasing the packet size and quantity in the network simulation. During burst traffic, the proposed approach gathers data from the MSs from optimal routes to the load balancing destination. In a sense, the MSs are prioritized for collecting burst traffic data. The MSs move towards the CHs where priority data needs to be collected. In this way, it effectively prevents packet loss and reduces the energy consumption. Therefore, the proposed method provides balanced energy consumption in the network through data collection based on an adaptive sink mobility model.

3.1. The Network Model of the Study

In the WSN, different numbers of the sensor nodes are uniformly allocated to the network area of different sizes. The WSN has a three-level heterogeneous structure, including normal, advanced and super nodes whose numbers are N in total and represented as N_{nrm}, N_{adv} and N_{sup} as in Equation (1). The normal, advanced, and super nodes have different characteristics from each other in terms of energy, data processing, transmission scope, communication, and many features. However, we assume that the nodes differ only in energy in this work. CHs are usually selected from the advanced and/or super nodes in the network instead of the normal nodes. Since the energies of all nodes can be close to each other when the energy balance is achieved in the network, CHs can also be selected from the normal nodes. The MS collecting data from the selected CH is assumed to have unlimited energy. The rest of the nodes in the network have normal node properties

$$N = N_{nrm} + N_{adv} + N_{sup.} \tag{1}$$

The advanced and super nodes have ω and φ times more energy than normal nodes, respectively. The energies of the normal, advanced and super nodes in the network can be given by Equation (2) - (4), E_{nrm}, E_{adv} and E_{sup}, respectively

$$E_{nrm} = E_0 x\ N_{nrm} \tag{2}$$

$$E_{adv} = E_0 x N_{adv} x (1 + \omega) \tag{3}$$

$$E_{sup} = E_0 x N_{sup} x (1 + \varphi. \tag{4}$$

Since ω and φ are energy coefficients, they are added by 1 fractionally. Accordingly, the total energy of the network (E_t) can be given as in Equation (5)

$$E_t = E_{nrm} + E_{adv} + E_{sup.} \tag{5}$$

3.2. The Burst Traffic Model of the Study

In this study, we define the burst traffic as the traffic load created by the excessive swollen and dense data obtained by the CHs from the environment and their cluster members. When normal and healthy data accumulates in a particular node so that the node cannot handle it, it can disrupt the functioning of the sensor node. On the other hand, some data may lose its capabilities due to physical or software failure in the sensor node. These harmful situations are the inspiration for the traffic scenarios in our study. For this reason, if the proposed algorithm detects or predicts that any CH node has burst traffic, the data is backed up on another node with the nearest and highest energy of the CH. In this way, the data is not lost and the sensor node loses its functionality. In burst traffic scenarios, the MS immediately moves to the backed-up node with this data so that it can properly collect the burst traffic data. In this way, the health of the CH is

guaranteed in this respect, and the risk of being lost and dropped by backing up the healthy and reliable data without deterioration is reduced. Although the length of the mobile path may increase due to the burst traffic routing, the MS increases the speed v_m towards the target at a certain rate, so the arrival time t_{ar} to the destination decreases. Simultaneously, the packet loss rate is significantly reduced as the number of packets falling on the network decreases. As a result, the packet delivery rate increases.

In the literature, an ON / OFF traffic distribution model has been proposed to model the network traffic [29]. The ON process indicates that the traffic flow continues; the OFF process indicates that the traffic flow is interrupted and sleep mode. According to this model, each node generates a traffic that follows a Poisson process with λ ratio, and then each node tracks one traffic. A bursty process is defined where packets are generated only when the transaction is ON. None of the previous models were based on heavy tail and similar burst traffic.

In this study, the N-BURST traffic model is proposed to model the traffic generated by cluster member nodes in the WSN. Here, ON and OFF statements are associated with logic "1" and logic "0", respectively. Performance measurements are obtained analytically, and it is decided that there is burst traffic in a CH under different B_{dec} burst parameters, and this data should be backed up.

The N-Burst 1/0 model used in our study is a derivative of the ON / OFF model. N-Burst is the combination of 1/0 type data traffic flows from N independent cluster members in a CH during the arrival process to the destination (CH). During "1" time, each source generates packets at the rate of λB_{dec} and does not generate packets for "0" time. Consider too many and fast data packets theoretically; if $\lambda B_{dec} \to \infty$, all packets in a data block arrive simultaneously, and the traffic model turns into a bulk output.
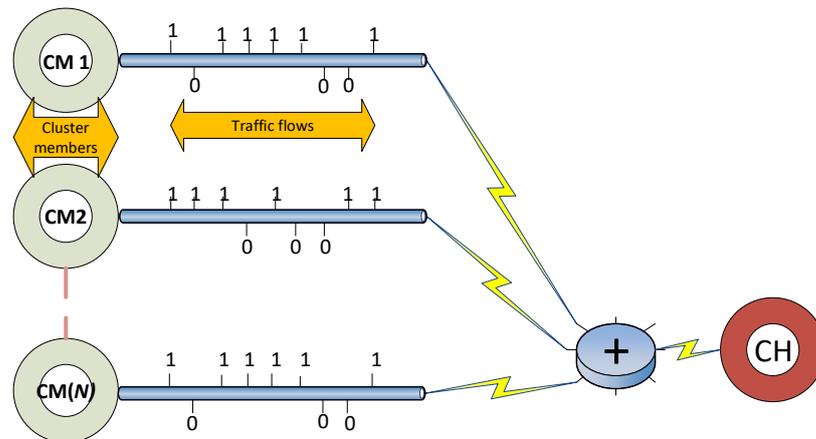
Figure 1. *N-Burst traffic model in the proposed study*

In the WSN topology, a cluster includes one or more sensor cluster member nodes (CMs). These nodes each generate data according to the 1-Burst traffic model. There is a CH that collects data generated by all CMs. The CMs can communicate directly with the CHs, as shown in Figure 1. In this way, we define the single node traffic model using the N-Burst traffic model. Assume that k is the average arrival rate for each node (average for 1 and 0 together), ∂ is the total arrival rate (packets per unit of time) generated by the nodes, where $\partial = kC_m$. Here, C_m is the number of member nodes in a cluster. These member nodes send data to only one CH. Consider that n_ρ and ∂_ρ are the average numbers of packets and peak transmission rate during a burst process, respectively. For a burst state, $1 = n_\rho / \partial_\rho$ is the average ON time. "0" is the average 0 (sleep time) time between bursts. Also, v is the average packet service rate of a CH (packets per time unit) and, $\rho = \partial / v$ is the CH utilization rate.

Based on all these explanations, the burstiness parameter B_{dec} is defined as in Equation (6)

$$B_{dec} = 1 - \frac{k}{\partial_\rho} . \tag{6}$$

In the WSN traffic network model, the burst traffic is decided by considering at the limiting conditions for $B_{dec} = 0$ and $B_{dec} = 1$ for all possible distributions. In order to decide on burst traffic due to buffer overflow probability which means sensor node failure, B_{dec} must be very close to "1". Since the source shortens a burst transmission time as the packet speed increases, it increases to the collective arrival limit at $B_{dec} = 1$. Also, this value is a monotonously increasing function of the B_{dec}. Using Equation (7), it is determined whether there is burst traffic using the burst traffic flag (BTF) for each CH.

Figure 2 shows the decision of the burst traffic according to the data retention rate of a CH. The data retention rate of a CH is the measure of the packets can be stored in a CH.
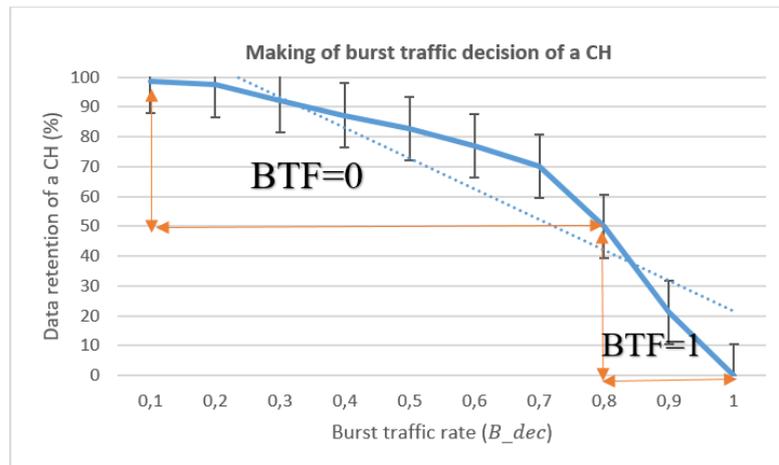
Figure 2. *Making the burst traffic decision according to the data retention rate of a CH*

From Figure 2, we understood that as the rate of burst traffic increases, the data retention rate of a CH decreases. Assuming that a CH can work with minimum half performance, while the B_{dec} value is 0.8, data retention rate falls below the percentage of 50. Therefore, the B_{dec} limit value is fixed at 0.8 when determining *BTF* value. For example, if B_{dec} is greater than 0.8, BTF is assigned as "1"; otherwise, the burst traffic decision is made as PTB = 0, which is noted as normal traffic/smooth traffic

$$BTF = \begin{cases} 1, & if \ B_{dec} \geq 0.8 \\ 0, & otherwise \end{cases}.$$ (7)

3.3. The Proposed Mobile Routing Model

The network includes two MSs with mobile path selection. The proposed sink mobility model has the feature of a controlled roaming model as the adaptive path selection is based on the movement method to the CH coverage limit and traffic-aware routing. Figure 3 shows the proposed group-clustered and burst-traffic awareness WSN topology. As seen in Figure 3, two MSs responsible for two different cluster groups collect the data sent by the sensor nodes from the CH. While the network structure is being formed, the MS nodes send a *"JoinRequest"* request message to be included in all CHs. According to Algorithm 1, these clusters have to choose one of the MSs. The relevant CHs agree to be included in the cluster group by sending the *"JoinAccept"* reply message to the MS. As a result, two different cluster groups are formed. The MS nodes collect data as soon as they are in the coverage area of a CH according to the proposed mobility model. The proposed routing model is also aware of the data with burst traffic. In fact, overly dense and swollen data have to be collected urgently. Otherwise, this data may be lost. For example, according to the proposed algorithm, the MS-1 should go to the CH-2 after the CH-1, whereas in order to collect the burst traffic data in the CH-8, it has to go to node *8x*, which is the closest to CH-8. The speed of the MS increases as it travels to the node with the burst traffic. In this way, data collection delay is reduced. Node *8x* is a sensor node that holds the lost data in the CH-8. In fact, there is the closest node that keeps a backup of each CH when it senses the burst traffic. Then, the MS-1 reaches the source point by visiting the other CHs 7, 2 and 3 respectively and completes a tour. In the cluster group, the MS-2 must go to the CH-

4 after visiting the CHs 10, 6, and 5, respectively, while the node *9y* keeps the backup of the nearest CH-9 in order to collect the burst traffic data in the CH-9. it has to go to node *9y,* which is the closest to CH-9. Then, the MS-2 visits the CH-4. Finally, it reaches the source point and completes a tour. In this way, packet loss can be significantly reduced with the burst traffic awareness mobility model.
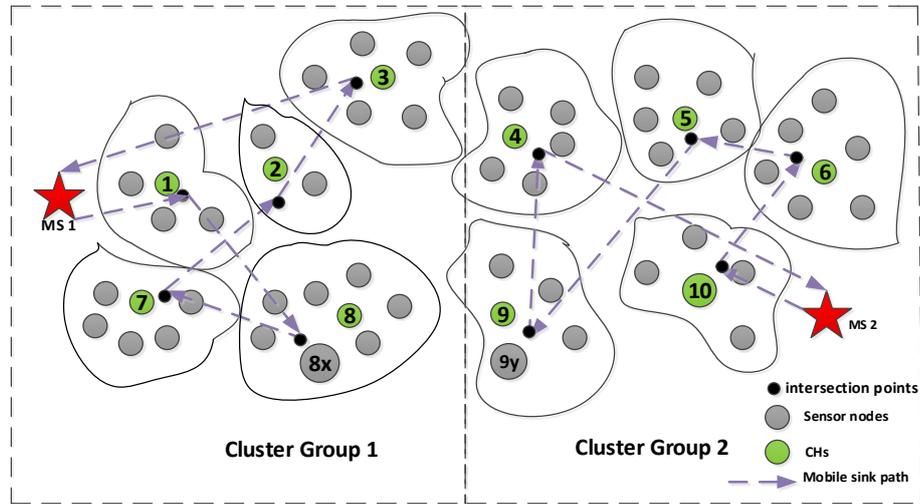
Figure 3. The proposed group-clustered and burst traffic awareness heterogeneous WSN topology

When the CHs are elected (CH^r), the CHs at several positions in the created graph are ranked by the CH ranking algorithm with weight-burst traffic (WBT-ranking) in Algorithm 1. The nodes in the initial graph are ranked not according to their number, but to the weight object (*w*) of the path trajectories in a graph where the paths including the locations of each CH. The MS selects a path with the minimum weight object from the list of all routes and travels accordingly.

Definition. We define a problem based on the vehicle routing problem (VRP) [30]. In Equation (8), it is aimed to minimize the lengths of the paths traveled by the MSs

$$x_{em} = \begin{cases} 1, & edge\ e\ had\ been\ visited\ by\ MS_m\ for\ round\ r. \\ 0, & otherwise \end{cases} \tag{8}$$

where x_{em} defines whether edge *e* had been visited by the MS_m within the in total *E* edges. Since there are two MSs in the network, *m* is assigned as 2. The edge length d_e is defined by in Equation (9). Therefore, all edge lengths should be minimized

$$Minimize\ \sum_{e\ \in E} d_e \sum_{m=1}^{2} x_{em}\ . \tag{9}$$

In Equation (10), y_{im} defines whether the node CH^r_i had been navigated by a MS for round *r* . Moreover, the sum of value of y_{im} is "1", because any node *i* in the CH^r set is visited by MS_m, represented as in Equation (11)

$$y_{im} = \begin{cases} 1, & CH^r_i\ had\ been\ visited\ by\ MS_m\ for\ round\ r \\ 0, & otherwise \end{cases} \tag{10}$$

$$\sum_{m=1}^{2} y_{im} = 1\ \forall\ i \in CH^r\ set \setminus \{0\}\ . \tag{11}$$

Since x_{em} and y_{im} are bidirectional nodes in relation to each other, Equation (12) should be satisfied

$$\sum_{e\ \in \gamma(i)} x_{em} = 2y_{im}\ \forall\ i \in CH^r\ set\ m{=}1{,}2 \tag{12}$$

where $\gamma(i)$ refers to the edge-node connection for the node i. Also, the edges are more than the nodes since the MSs visit the nodes in the set all CH^r for the round r. The MSs return to the starting point for the next round. So, the condition of $x_{em} \geq 2y_{jm}$ should be satisfied as in Equation (13)

$$\sum_{e \in \gamma(S)} x_{em} \geq 2y_{jm} \ \forall \ i \ CH^r \ set \setminus \{0\}, j \in \ S, m=1,2 . \tag{13}$$

To address this problem, we propose Algorithm 1 that can be defined as Equations (15) - (17) in the Solution.

Solution. CH ranking algorithm with weight-burst traffic.

In Equation (14), z_{im} determines whether the CH node i has burst traffic belonging to the MS_m

$$z_{im} = \begin{cases} 1, & if \ BTF = 1 \\ 0, & if \ BTF = 0 \end{cases} . \tag{14}$$

Thereby, Equation (15) is formulated to compute the path designs for all CHs using x_{em}, y_{im} and z_{im}, respectively

$$Minimize \ _{1 \leq m=2}^{max} \sum_{e \in E} d_e \ x_{em} \frac{\sum_{i \in CH^r \ set} y_{im*} z_{im}}{2*v_m} \tag{15}$$

where v_m is the velocity of a MS. The expression in the Equation (15) is minimized and many MS path routes are defined as Y. Then, a graph is used to save the obtained Y paths by the weight-order. Once a graph is expressed as $G = (V, E)$ and its relation to a given source (s) -destination (d) given s - d, there is a mobile path between $Y = \{Y_1, \ldots \ldots, Y_T\}$. T is the number of the mobile routes. The weight (w) of a path is defined as in Equation (16)

$$w = w(Y) = \sum_{i=1}^{T} w_i (Y_i) + \sum_{i=1}^{T-1} c * (Y_i, Y_{i+1}) \tag{16}$$

$$c = \frac{1}{B_{dec}} . \tag{17}$$

It is assigned as the minimum mobile path with minimum w. The property of the c value that determines the w is determined according to Equation (17) with the weight parameter and the burst traffic belonging to a CH in a path. y[i, j]= $Y^{(ij)} \ldots Y^{(ij)}$ j−i+1 is similar paths where Y_{cost} [i, k] and Y_{cost} [k + 1, j] mean combining the two sequences. The pseudo code of the WBT-ranking is given in Algorithm 1. $Y = VRP(G)$ is defined by the Solution according to Algorithm 1. Finally, the path Y_{cost}' with the lowest cost is used to determine the mobile route of the a MS as $P(t)$.

The primary purpose here is to determine the MS routes with the shortest possible way and create an adaptive-effective and burst traffic aware MS mobility model. In fact, the MS path route is determined sequentially according to Algorithm 1.

The burst traffic aware adaptive mobility model (BTAMM) is presented as a pseudo code in Algorithm 2. When determining the trajectories of the MSs, the average ratio of the cost of the route is taken into account. A protocol uses this ratio to the cost of the optimal mobile route for the same network history. It is considered that the path used in a session may change over time due to network dynamics such as topology changes. While finding the shortest path of the MSs within the cluster groups, the dynamic programming method typically subjected to optimization problems is used. All possible paths in the set group are recorded in a $G(V, E)$ graph. In this graph, the MS_1 and MS_2 are grouped as $MS = KNN(G)$ according to the k-nearest classification model. Then, Algorithm 1 is applied to the group of the CHs that are included in the set P to which MS is connected, and C_1 and C_2 which are sequential CH sets are obtained. After that, $CIP(i)$ is determined in order to find the location points of the CHs. After that, the distances of the d_{c_i} intersection

points are determined, and these distances are assigned as $\widehat{C_1}$ and $\widehat{C_2}$. Finally, these lengths are saved as $p_1(t)$ and $p_2(t)$ as the mobile paths of the MS-1 and MS-2, respectively.

Algorithm 1 The CH ranking algorithm with weight-burst traffic (WBT-ranking)

Input : $G(V, E)$, r.

Output: $P(t)$

1: $Y = VRP(G)$, $Y = \{Y_1, Y_2, Y_3, \dots Y_T\}$
2:    **for** $i = 1 \: to \: T$ **do**
3:       $y[i, j] \leftarrow Y^{(ij)}$
4:       $Y_{cost}[i, j] \leftarrow w(Y^{(ij)})$
5:        **while** $Minimized \: value < k < j$ **do**
6:         $Y_{cost}' = \{Y_{cost}[i, k] + Y_{cost}[k + 1, j]\}$
7:          **if** $Y_{cost}' \leq Y_{cost}[i, j]$ **then**
8:           $y[i, j] \leftarrow Y_{cost}'$
9:         $P(t) \leftarrow y[i, j]$
10:         **end if**
11:      **end while**
12: **end for**
13: **return** $P(t)$

Algorithm 2 Burst traffic aware adaptive mobility model (BTA-MM)

Input: $G(V, E)$, r.

Output: $p_1(t)$, $p_2(t)$

1: $MS = KNN(G), MS = \{MS_1, MS_2\}, P = \{CH_1, CH_2, CH_3, \dots., CH_n\}$
2:    **for all** $CH_i \in P$ **do**
3:      **if** $CH_i \in MS1$ **then**
4:       $C_1 \leftarrow WBTsort(MS1)$
5:        **while all** $CH_i.CIP(i) \in C_1$ **do**
6:         $c_i \leftarrow C_1.CIP(i);$
7:         $\widehat{C_1} = \widehat{C_1} \cup \{d_{c_i}\}$
8:       **end while**
9:     **else**
10:       $C_2 \leftarrow WBTsort(MS2)$
11:        **while all** $CH_i.CIP(i) \in C_2$ **do**
12:         $c_i \leftarrow C_2.CIP(i)$
13:         $\widehat{C_2} = \widehat{C_2} \cup \{d_{c_i}\}$
14:       **end while**
15:     **end if**
16:    **end for**
17:    **for** $i = 0$ to $P.length() + 1$ **do**
18:       add $\widehat{C_1}$ to $p_1(t), t = 2i$
19:       add $\widehat{C_2}$ to $p_2(t), t = 2i$
20:    **end for**
21: **return** $p_1(t) \: and \: p_2(t)$

4. PERFORMANCE EVALUATION

4.1. Simulation Setup

The proposed method called BTA-MM is compared with the existing methods DPPMSBT [17], MEACBM [12] and EGRPM [18] through performance simulations using the NS-2 installed on the Ubuntu 14.04 LTS operating system. We present Table 1 for the simulation parameters used in this study. The performance criteria, including network lifetime, average energy consumption, average mobile path length, and network throughput are used for performance analysis in the simulations.

Table 1. *The simulation parameters*

Parameters	Value	Parameters	Value
Network simulator	NS-2	Antenna type	Omni Anten
Total number of nodes (N)	100-500	Propagation type	Two ray ground
Network area	200x200 m²-500x 500 m²	Application layer protocol	CBR
Number of normal nodes (N_{nml})	$N * 0.6$	Transport layer protocol	UDP
Number of advanced nodes (N_{adv})	$N * 0.3$	MAC layer protocol	802.15.4 (Zigbee)
Number of super nodes (N_{sup})	$N * 0.1$	Simulation time	200 sec
Initial energy of normal nodes	1 J	N_{ack}	200 bits
Initial energy of advanced nodes	2 J	p	0.2
Data amount (l)	2000 bits	k	2500
Communication range (CR)	30 m	A	40
Node distribution	Uniformly	t_{elec}	0.3x10⁻³ sec
Base station (BS)	(0,0)	N_{cog}	4000
		v	150 packets/sec
Interface type	Phy/Wirelessphy	∂_ρ	10
Traffic queue type	Droptail/Priority Queue	∂	50 packets
		$\propto$	0.01
		ω	0.02
		φ	0.03

The heterogeneous network model is shown in Figure 4 with clustering formation for 100 nodes deployed at a network size of 500 x 500 m². In the network, the CHs are represented by nodes painted in red, while others are black painted nodes. The green-colored MS-1 and MS-2 represent the mobile sinks belonging to cluster group1 and 2, respectively. From Figure 4, it is understood that once the MSs arrive on the coverage intersection points (CIPs) of the CHs, the MSs collect the data from these nodes. In addition, the mobile paths of the MS-1 and MS-2 are formed independently of each other. The total path length of the MSs is computed as the sum of the path length of two MSs. Thereby, depending on the node traffic jam, data collision in the network is decreased as much as possible, enhancing the network's energy efficiency. Two scenarios, including WSN-1 and WSN-2, have been designed in the simulations. The WSN-1 and WSN-2 denote that the network consists of 200 by 200 m and 500 by 500 m network sizes in the simulation scenarios.
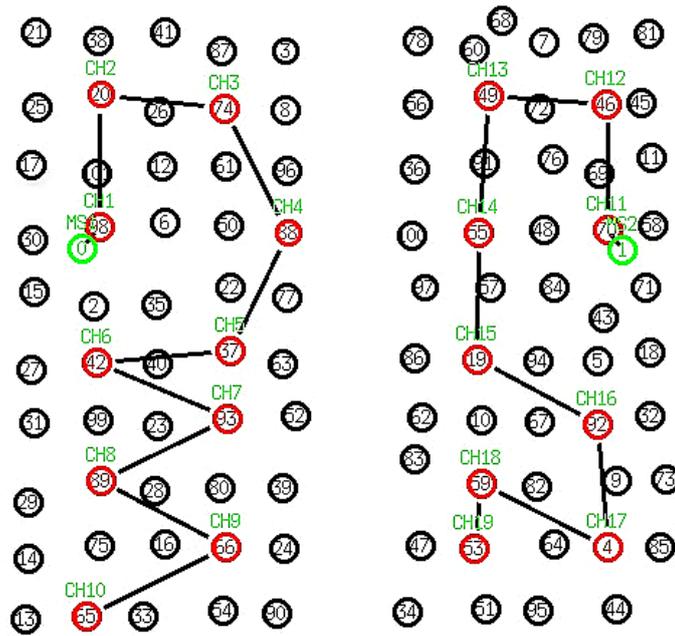
Figure 4. *The mobile paths of the MS-1 and MS-2 obtained in the clustered WSN topology*

4.2. Performance Analysis

In this section, the proposed method has been compared with the existing methods in terms of performance criteria, including network lifetime, average energy consumption, average mobile path length, and network throughput.

The network lifetime is known as the total number of rounds when all nodes died. In this performance analysis, the sensor nodes ranging from 100 to 500 nodes are distributed in the network field to analysis the network lifetime in terms of its density. The proposed method has been evaluated among all algorithms with two scenarios, including WSN-1 and WSN-2. From Figure 5(a), it is understood that while the network life is achieved at 14528 rounds with the proposed method in a 100-node network, with EGRPM, MEACBM, and DPPMSBT methods, the network lifetime is achieved at 12761, 11245, and 9820 rounds, respectively. Figure 5(a) and 5(b) show that as the number of nodes increases, the network lifetime also increases. As shown in Figure 5(a), while the network life is achieved at 69843 rounds with the proposed method in the 500-node network, with EGRPM, MEACBM, and DPPMSBT methods, the network lifetime is achieved at 62749, 57267, and 46878 rounds, respectively. It is observed from Figure 5(b) that as the network area increases, the network lifetime for all algorithms decreases. As seen from Figure 5(b), while the network lifetime is achieved at 13478 rounds with the proposed method in the 100-node network, with EGRPM, MEACBM, and DPPMSBT methods, the network lifetime is achieved at 11974, 9785, and 7748 rounds, respectively. When the proposed method is carried out, the network lifetime is achieved at 64924 rounds as the highest in a 500-node and 500 by 500 m network size. As can be seen, the highest performance has been achieved with the proposed method. This is due to the proposed methods discover the mobile paths of the MSs. Tables 2 and 3 present all the performance results of the network lifetime for WSN-1 and WSN-2, respectively.
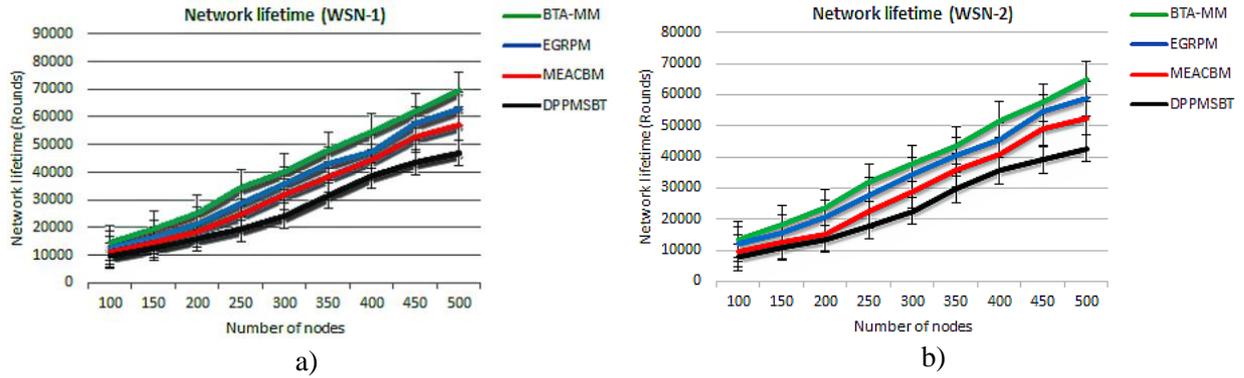
Figure 5. *Analysis results of the network lifetime based on the number of nodes a) WSN-1 b) WSN-2*

Table 2. *Analysis results of the network lifetime based on the number of nodes for WSN-1*

Algorithms	Number of nodes								
	100	150	200	250	300	350	400	450	500
	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1
DPPMSBT	9820	12675	15986	19574	24495	31481	38872	43415	46878
MEACBM	11245	14713	18732	24676	31872	38470	44593	52948	57267
EGRPM	12761	16648	21475	28571	35784	43195	47451	57742	62749
BTA-MM (Proposed)	**14528**	**19624**	**25423**	**34538**	**40293**	**47847**	**54763**	**62079**	**69843**

Table 3. *Analysis results of the network lifetime based on the number of nodes for WSN-2*

Algorithms	Number of nodes								
	100	150	200	250	300	350	400	450	500
	WSN-2	WSN-2	WSN-2	WSN-2	WSN-2	WSN-2	WSN-2	WSN-2	WSN-2
DPPMSBT	7748	10967	13674	17891	22573	29650	35713	39140	42678
MEACBM	9785	12682	15249	22478	28785	35852	40899	48914	52513
EGRPM	11974	15785	20573	27762	34274	40651	45428	54467	58710
BTA-MM (Proposed)	**13478**	**18274**	**23782**	**31769**	**37891**	**43678**	**51787**	**57418**	**64924**

We define the average energy consumption as the average amount of energy consumed by the nodes in the network, as given in Equation (18). Here, N_{ec} and R is the total amount of energy consumed and a number of total rounds in the network. The proposed algorithm has been evaluated among all algorithms with two scenarios, including WSN-1 and WSN-2. The nodes ranging from 100 to 500 nodes are deployed in the network area to analysis the average energy consumption in terms of its density. From Figures 6(a) and 6(b), it is observed that the lowest average energy consumption is achieved with the proposed algorithm. For example, Figure 6(a) presents that in a 100-node network, while the average energy consumption is obtained 0.0105 J with the proposed algorithm, with EGRPM, MEACBM, and DPPMSBT methods, the average energy consumption is obtained as 0.0119, 0.0135, and 0.0155 J, respectively. From Figure 6(a), it is observed that while the average energy consumption is obtained 0.011 J with the proposed algorithm in a 500-node network, with EGRPM, MEACBM, and DPPMSBT methods, the average energy consumption is obtained as 0.0133, 0.0154, and 0.0195 J, respectively. From Figure 6(b), it is observed that the average energy consumption is increased in all algorithms for large-scale networks. On the other hand, the minimum average energy consumption is experienced by the proposed method. The proposed method presents the best performance. Tables 4 and 5 present all the performance results for average energy consumption for WSN-1 and WSN-2, respectively

$$E_{avg} = \frac{N_{ec}}{R} \cdot \qquad (18)$$
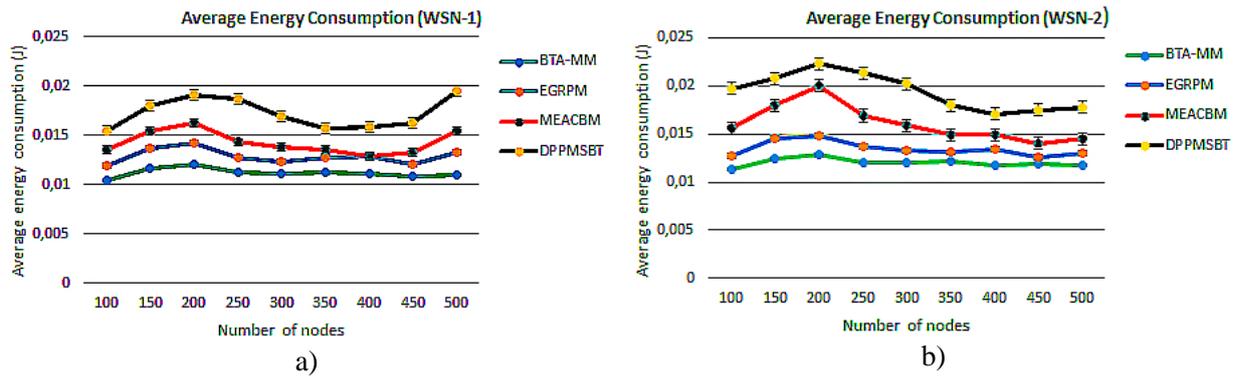
Figure 6. *Analysis results of the average energy consumption based on the number of nodes*
a) WSN-1 b) WSN-2

Table 4. *Analysis results of the average energy consumption based on the number of nodes for WSN-1*

Algorithms	Number of nodes								
	100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1
DPPMSBT	0.0155	0.018	0.0191	0.0187	0.0169	0.0157	0.0158	0.0162	0.0195
MEACBM	0.0135	0.0155	0.0163	0.0143	0.0138	0.0136	0.0129	0.0133	0.0154
EGRPM	0.0119	0.0137	0.0142	0.0128	0.0123	0.0128	0.0119	0.0121	0.0133
BTA-MM (Proposed)	**0.0105**	**0.0116**	**0.012**	**0.0113**	**0.0111**	**0.0112**	**0.0111**	**0.0109**	**0.011**

Table 5. *Analysis results of the average energy consumption based on the number of nodes for WSN-2*

Algorithms	Number of nodes								
	100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1
DPPMSBT	0.0197	0.0208	0.0223	0.0213	0.0202	0.018	0.0171	0.0175	0.0178
MEACBM	0.0156	0.018	0.02	0.0169	0.0159	0.0149	0.0149	0.014	0.0145
EGRPM	0.0127	0.0145	0.0148	0.0137	0.0133	0.0131	0.0134	0.0126	0.013
BTA-MM (Proposed)	**0.0113**	**0.0125**	**0.0128**	**0.012**	**0.012**	**0.0122**	**0.0117**	**0.0119**	**0.0117**

Using Algorithm 2, the path length visited by the MS-1 and MS-2 is determined as $p_1(t)$ and $p_2(t)$, respectively. On the other hand, the $p_1(t)$ and $p_2(t)$ are calculated for only one round. Hence, the total path length $PL(t)$ taken during the network lifespan R is computed using Equation (19). As a result, the average mobile path length $PL(t)_{avg}$ had over the network life is calculated using Equation (20). In this analysis, the nodes ranging from 100 to 500 nodes are deployed in the network area to analysis the network performance in terms of its density. The proposed algorithm has been evaluated among all algorithms with two scenarios, including WSN-1 and WSN-2. From Figures 7(a) and 7(b), when all algorithms are run, it is observed that the average mobile path length increases as the number of nodes increases. From Figure 7(a), it is observed that while the average mobile path length is achieved at 985 m in the 100-node network, with EGRPM, MEACBM, and DPPMSBT methods, the average mobile path length is achieved at 1148, 1286 and 1538 m, respectively. From Figure 7(b), it is understood that although the average mobile path length is obtained as 3852 m with the proposed method in the 500-node network, with EGRPM, MEACBM, and DPPMSBT methods, the average mobile path length is obtained as 4126, 4678, and 5122 m, respectively. In the proposed algorithm, the minimum mobile path length has been succeeded, although there is a mobile routing burst traffic control of the CHs with dense packets. One of the most important reasons for this is that the mobility model between the CHs can be provided by the adaptive and optimum ways. Tables 6 and 7 present all the performance results of the average mobile path length for the WSN-1 and the WSN-2, respectively

$$PL(t) = \sum_{r=1}^{R} p_1(t)^r + p_2(t)^r \tag{19}$$

$$PL(t)_{avg} = \frac{PL(t)}{R}. \tag{20}$$
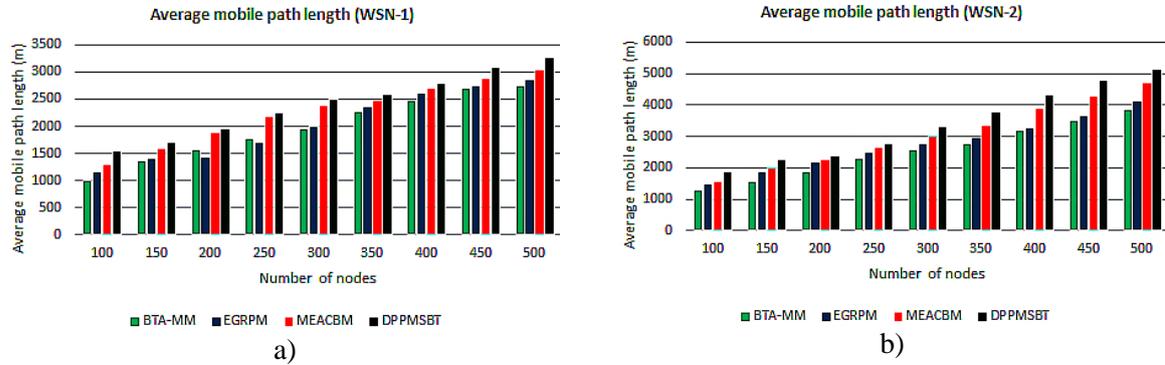
Figure 7. *Analysis results of the average mobile path length based on the number of nodes*
a) WSN-1 b) WSN-2

Table 6. *Analysis results of the average mobile path length based on the number of nodes for WSN-1*

Algorithms	Number of nodes								
	100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1
DPPMSBT	1538	1697	1943	2232	2486	2586	2790	3073	3248
MEACBM	1286	1576	1869	2180	2369	2467	2684	2874	3025
EGRPM	1148	1389	1424	1698	1999	2357	2594	2738	2848
BTA-MM (Proposed)	**985**	**1356**	**1568**	**1759**	**1947**	**2258**	**2473**	**2691**	**2730**

Table 7. *Analysis results of the average mobile path length based on the number of nodes for WSN-2*

Algorithms	Number of nodes								
	100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1	WSN-1
DPPMSBT	1862	2249	2368	2751	3288	3762	4293	4768	5122
MEACBM	1543	1986	2248	2630	2964	3347	3874	4255	4678
EGRPM	1486	1837	2175	2486	2759	2954	3246	3647	4126
BTA-MM (Proposed)	**1258**	**1562**	**1864**	**2275**	**2567**	**2763**	**3170**	**3468**	**3852**

Network throughput (efficiency) has been analyzed during the simulation in order to evaluate the network performance of the proposed method in more detail. In this study, the network throughput is defined as the measure of how fast data on the network can be transmitted to the BS. To do this analysis, 100 nodes are deployed over a 200 by 200 m network area. In this analysis, the effect of CHs with burst traffic on network performance has been examined for 200 seconds. The simulations have been executed in which the total CHs in the network have burst traffic varying between 10 and 80 as a percentage. We assume that all CHs with burst traffic in the network will unacceptably worsen the efficiency of the network. As shown in Figure 8, in the network where there are a percentage of 10, 20, 40 and 80 of CHs during the simulation, the network throughput suddenly decreases after 192, 184, 176 and 174th seconds, respectively. Note that even though there are a percentage of 80 of the CHs in the network until these times, the network throughput does not fall below 50 percent. This is because the number of alive nodes in the network decreases more after these times. Having too few nodes in the network to fully communicate data causes the network to consume its energy faster. As a result, the network throughput decreases catastrophically. The conclusion to be drawn here is that in order to keep the network throughput at a high level, data with burst traffic should be collected

in a timely and accurate manner. Otherwise, the improvement of the network performance cannot be guaranteed.
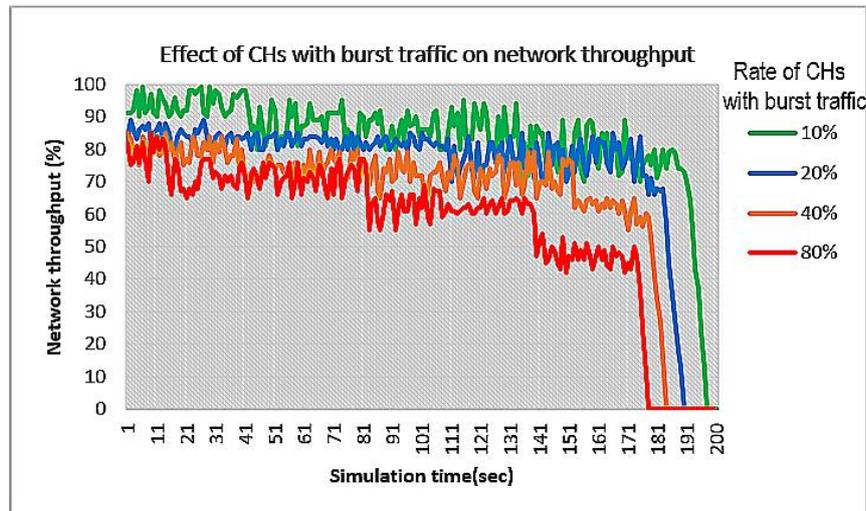
***Figure 8.** The analysis of the network throughput in the proposed method*

5. CONCLUSION AND FUTURE WORK

In this study, a burst traffic-aware mobile routing technique is presented in order to address the network lifetime, energy consumption, mobile path detection and burst data traffic problems in heterogeneous WSNs. In the proposed technique, two different methods are presented. In the first method, the CH ranking algorithm per cluster (WBT-ranking) is developed according to weight-burst traffic value. In the second method, the burst traffic aware adaptive mobility model (BTAMM) is proposed. Once these methods are executed, as soon as the MSs enter the boundary of all CHs, they collect all the data in a single-hop communication and collect all the data in the network. The proposed method in this study can be adapted for real WSN applications with Unmanned Aerial Vehicles (UAV) embedding since it succeeds in routing the shortest mobile path. In the proposed method, when the mobile sink node is considered to be a moving UAV, the CHs can also be defined as the target points of the UAVs. UAVs can forward the data in the network to the BS by completing their routes from the target addresses determined according to various criteria in the WSN. In this way, data loss on the network is reduced, increasing the network lifespan and reducing the mobile path length that the UAV visits the network. To compare the proposed protocol with existing studies, performance analyzes have been performed on the NS-2 simulation platform based on the criteria of the network lifetime, average energy consumption, and average mobile path length. In addition, the network throughput of the proposed method has been analyzed during the simulation duration. Moreover, the effect of the CH rate with burst traffic on network efficiency has been investigated. The simulation results illustrate that the proposed method enhances the network performance more than other studies. From the performance results, we observe that the proposed method increased the network lifetime by approximately 42.5%, 27.4%, and 11.1% in networks with 100 nodes installed in 500 by 500 m area compared to the DPPMSBT, MEACBM, and EGRPM methods, respectively. On the other hand, optimization problems have not been taken into consideration in the proposed methods. For this purpose, integrating optimization-based methods in clustering and routing mechanism may address the limitation of the proposed methods. So, in future works, we plan to propose a more efficient CH selection and MS mobility model by integrating the proposed method with optimization methods.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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