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Endurance and Efficiency Void Unfolding Study in Data Group Wireless Sensor Network

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***Abstract*— In Wireless sensor network, network lifetime plays an important role for data gathering process. In WSN, battery powered sensor nodes sense the environment at the transmission and collect the data from source node and forward to the sink node. The proposed techniques such as analytic model to increase the transmission power during routing process. We theoretically estimate the traffic load, energy consumption, and lifetime of sensor nodes during the entire network lifetime. Furthermore, we investigate the temporal and spatial evolution of energy hole, and apply our analytical results to WSN routing in order to balance the energy consumption and improve the network lifetime. Extensive simulation results are provided to demonstrate the validity of the proposed analytic model in estimating the network lifetime and energy hole evolution process.**

***Index Terms*— Wireless Sensor Networks (WSN), energy hole evolution, network lifetime.**

I. INTRODUCTION

Wireless sensor networks (WSNs), which are capable of sensing, computing, and wireless communication, are widely applied to many applications such as military surveillance, environmental monitoring, infrastructure and facility diagnosis, and other industry applications. A data-gathering WSN consists of a large number of battery-powered sensor nodes that sense the monitored area and periodically send the sensing results to the sink. Since the battery-powered sensor nodes are constrained in energy resource and generally deployed in unattended hostile environment, it is crucial to prolong the network lifetime of WSN. Meanwhile, as energy consumption is exponentially increased with the communication distance according to the energy consumption model, multi-hop communication is beneficial to data gathering for energy conservation. However, since the nodes close to the sink should forward the data packets from other nodes, they exhaust their energy quickly, leading to an energy hole around the sink. As a result, the entire network is subject to premature death because it is separated by the energy hole. There have been several existing works studying the energy consumption and network lifetime analysis for WSNs. Most of them focus on the duration from network initialization to the time when the first node dies (i.e., First Node Died Time, FNDT), aiming to improve the network performances and optimize the FNDT. Although most of existing works are effective to estimate FNDT, the period from FNDT to the time when all the sensor nodes are dead or the network is completely disabled (i.e., All Node Died Time, ANDT) is relatively long .For most applications, a small portion of dead nodes may not cause a network failure, although they can impact the network performances

Energy hole is crucial and challenging for lifetime analysis in WSNs, because it can lead to a premature death of the network.Olariu et al. first prove that the energy hole problem is inevitable in the WSN under some specific conditions. Perillo et al. analyze in what condition the energy holes could appear. Rahim et. al. discuss the load balancing techniques to mitigate energy hole problem in large- scale WSNs, and propose a distributed heuristic solution to balance the energy consumption of sensor nodes by adjusting their transmission power. The energy hole problem has also been studied in cluster-based WSNs. Most of the existing works , that energy hole locates around the sink, and design energy-efficient routing protocols to mitigate the unbalanced energy consumption and prolong the network lifetime. However, recent investigations point out that energy hole does not always emerge close to the sink and highly depends on some network parameters, such as the energy consumption model and transmission range of sensor nodes. However, theoretic analysis is not provided in existing works to estimate the emerging time and location of the energy hole, as well as its evolution process.

II. RELATED WORK

In recent years, the use of wireless sensor networks for industrial applications has rapidly increased. However, energy consumption still remains one of the main limitations of this technology. As communication typically accounts for the major power consumption, the activity of the transceiver should be minimized, in order to prolong the network lifetime. To this end, in [1] Giuseppe Anastasi, Marco Conti and Mario Di Francesco proposed an adaptive staggered sleep protocol (ASLEEP) for efficient power management in wireless sensor networks targeted to periodic data acquisition. This protocol dynamically adjusts the sleep schedules of nodes to match the network demands, even in time-varying operating conditions. In addition, it does not require any a priori knowledge of the network topology or traffic pattern. ASLEEP has been extensively studied with simulation. The results obtained show that, under stationary conditions, the protocol effectively reduces the energy consumption of sensor nodes (by dynamically adjusting their duty-cycle to current needs) thus increasing significantly the network lifetime. With respect to similar nonadaptive solutions, it also reduces the average message latency and may increase the delivery ratio. Under time-varying conditions, the protocol is able to adapt the duty-cycle of single nodes to the new operating conditions, while keeping a consistent sleep schedule among sensor nodes. The results presented here also confirmed by an experimental evaluation in a real testbed.

The problem of data sampling and collection in wireless sensor networks (WSNs) is becoming critical as larger networks are being deployed. Increasing network size poses significant data collection challenges, for what concerns sampling and transmission coordination as well as network lifetime. In [2], Carlo Caione, DavideBrunelli and Luca Benini consider a scenario in which a large WSN, based on ZigBee protocol, is used for monitoring (e.g., building, industry, etc.). The approach is fully distributed: each node autonomously takes a decision about the compression and forwarding scheme to minimize the number of packets to transmit. Performance is investigated with respect to network size using datasets gathered by a real-life deployment. An enhanced version of the algorithm is also introduced to take into account the energy spent in compression. Experiments demonstrate that the approach helps finding an optimal tradeoff between the energy spent in transmission and data compression.

A multi-interface ZigBee building area network (MIZBAN) for a high-traffic advanced metering infrastructure (AMI) for high-rise buildings was developed. This supports meter management functions such as Demand Response for smart grid applications. To cater for the high-traffic communication in these building area networks (BANs), a multi-interface management framework was defined and designed to coordinate the operation between multiple interfaces based on a newly defined tree-based mesh (T-Mesh) ZigBee topology, which supports both mesh and tree routing in a single network. To evaluate MIZBAN, an experiment was set up in a five-floor building. Based on the measured data, simulations were performed to extend the analysis to a 23-floor building. These revealed that MIZBAN yields an improvement in application-layer latency of the backbone and the floor network by 75% and 67%, respectively. in [3] Hoi Yan Tung, Kim Fung Tsang and Kwok Tai Chui proposed the design engineer with seven recommendations for a generic MIZBAN design, which will fulfill the requirement for demand response by the U.S. government, i.e. a latency of less than 0.25 s.

A fundamental challenge in the design of Wireless Sensor Network (WSN) is to enhance the network lifetime. The area around the Sink forms a bottleneck zone due to heavy traffic-flow, which limits the network lifetime in WSN. [4] paper work attempts to improve the energy efficiency of the bottleneck zone which leads to overall improvement of the network lifetime by considering a duty cycled WSN. An efficient communication paradigm has been adopted in the bottleneck zone by combining duty cycle and network coding. Studies carried out to estimate the upper bounds of the network lifetime by considering (i) duty cycle, (ii) network coding and (iii) combinations of duty cycle and network coding. The sensor nodes in the bottleneck zone are divided into two groups: simple relay sensors and network coder sensors. The relay nodes simply forward the received data, whereas, the network coder nodes transmit using the proposed network coding based algorithm. Energy efficiency of the bottleneck zone increases because more volume of data will be transmitted to the Sink with the same number of transmissions. This in-turn improves the overall lifetime of the network. Performance metrics, namely, packet delivery ratio and packet latency have also been investigated. A detailed theoretical analysis and simulation results have been provided to show the efficacy of the proposed approach.

Opportunistic routing is widely known to have substantially better performance than unicast routing in wireless networks with lossy links. However, wireless sensor networks are usually duty cycled, that is, they frequently enter sleep states to ensure long network lifetime.This renders existing opportunistic routing schemes impractical, as they assume that nodes are always awake and can overhear other transmissions. In [5] article the authors introduce ORW, a practical opportunistic routing scheme for wireless sensor networks. ORW uses a novel opportunistic routing metric, EDC, that reflects the expected number of duty-cycled wakeups that are required to successfully deliver a packet from source to destination. they devise distributed algorithms that find the EDC-optimal forwarding and demonstrate using analytical performance models and simulations that EDC-based opportunistic routing results in significantly reduced delay and improved energy efficiency compared to traditional unicast routing. In addition, we evaluate the performance of ORW in both simulations and testbed-based experiments.

III. PROPOSED FRAMEWORK

A. *Network Model and Problem Statement*

Consider a data-gathering WSN, where n homogeneous sensors are randomly deployed in a circular region with the sink (base station) located at the centre. The network radius is R and the transmission range of each sensor is r. The sensor nodes are uniformly distributed in the network with a node densityρ. Each sensor monitors a specific area and periodically sends the sensed data to the sink in a data period (or data round). Therefore, network lifetime can be measured by the number of data periods (or rounds). All the sensed data are delivered to the sink using greedy geographic routing. Sensor nodes forward packets to one of their neighboring nodes, which are geographically closest to the sink among all the neighbors. Geographic routing is scalable for large WSNs, since it only requires local information to make forwarding decisions. This routing scheme has been widely adopted in multi-hop wireless sensor and ad-hoc networks. In addition, our network is based on a collision-free MAC protocol without data loss just as the assumptions in, then we can focus on the impact on the network lifetime caused by the routing protocol, to provide a significant guidance for routing design on the network layer.

Sensors operate in active mode or sleep mode. The ratio of the time in active mode to a total data period is called duty cycle, denoted by Υ. In general, sensors consume energy mainly in data receiving and transmitting, and idle listening when they are in active mode. We do not consider the energy consumption in sleep mode because it is small enough to be neglected.

Estimation on Nodal Traffic Load, Energy Consumption, and Network Lifetime Characteristics

In this section, we theoretically estimate the traffic load and energy consumption of sensor nodes, as well as the duration of each network stage based on our system model.

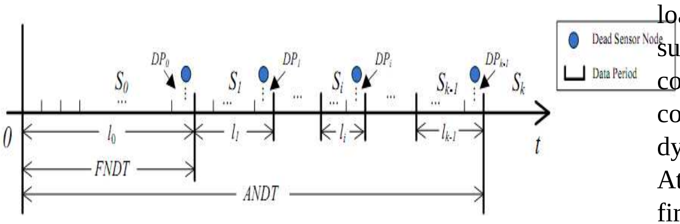


Fig. 1.Description of the entire process of network lifetime.

The main idea of the analytic model can be described as follows. We first divide the network into a number of small regions where the nodes have similar distances to the sink. Since the energy consumption of the sensor nodes in the same region (i.e., with the similar distances to the sink) should be the same from a statistical point of view, we use the average energy consumption of this region as the nodal energy consumption of this region. Fig. 2 shows a sector zone of the network, where A_x is a region with the width of ε and θ is the angle formed by A_x and the sink. The nodes' distances to the sink in A_x equal or are close to x. Since the nodal transmission radius is r, A_x is supposed to forward the data from A_{x+r}whose distance to A_x is r. Likewise, A_{x+r}relays the data from A_{x+2r}. However, if the divided region is relatively large (i.e., ε is relatively large), the energy consumption of the sensor nodes in it cannot be balanced. On the other hand, if the divided region is too small, there might be no node in this region.

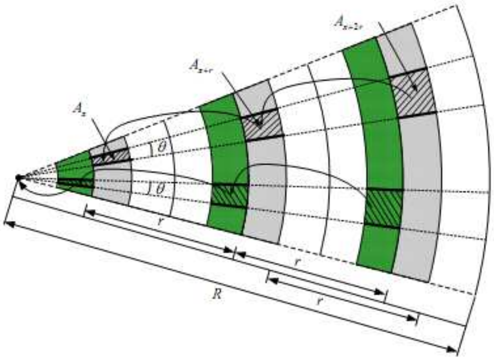


Fig. 2 Dataforwarding model.

A. Traffic Load Analysis at S_0

S_0 indicates a stage when no node dies, and hence is the most important stage with the best performance. We first analyze the traffic load of sensor nodes based on our analytic model described above, by the following theorem.

B. Energy Consumption Analysis at S_0 and Estimation of l^0

The traffic load of sensor nodes at S_0 can be determined by Algorithm 1. If each data packet contains τ bits, the total amount of transmitted data is $p_x^0\tau$. In this paper, energy consumption for network control is not considered since it is almost the same for each node and relatively small in greedy geographic routing. Therefore, we determine the energy consumption of sensor nodes at S_0 in the following theorem.

The energy consumption of node j consists of the following three parts

(a) Energy consumption for data receiving
(b) Energy consumption for data transmitting.
(c) Energy consumption for idle listening.

C. Estimation on Traffic Load, Energy Consumption and Network Lifetime from S_1 to S_{k-1}

In the previous subsections, we have determined the traffic load and energy consumption of sensor nodes at S_0. In this subsection, we analyze the traffic load and energy consumption of the sensor nodes after S_0, which is complicated because network routing paths change dynamically after S_0.

At first, we should find out that which part of sensor nodes die first. According to the sensor nodes with the maximum energy consumption will die first. According to our analytic model, the energy consumption of the sensor nodes in a region with width of ε are the same and the energy consumption of the regions with the same distance to the sink should be the same too. Therefore, the network can be divided into a number of ring regions with the same energy consumption and the width of ε. Without loss of generality, we set the first batch of dead nodes in the ring region of [u; u + ε], the number of dead nodes is $(\pi (u +\varepsilon)^2-\pi u^2).\rho$.

Algorithm 1

Determining the traffic load, energy consumption and lifetime of sensor nodes at each network stage.

Input: Network radius R, transmission radius r, node density of the network and other parameters.

Output: For each stage i and each node j, return the nodal traffic load $p_j^{(i)}$ energy consumption $e_j^{(i)}$ as well as theenergy transfer function *f* and lifetime vector *l*.

```
1: Determine the traffic load and energy consumption of each node at stage S0, i.e.[$p_1^{(0)},p_2^{(0)},\dots,p_j^{(0)},\dots.,p_n^{(0)}$] and [$e_1^{(0)}, e_2^{(0)},\dots e_j^{(0)},\dots.e_n^{(0)}$], according to Thm. 1and
2: $i = 1$;
3: while the sink can receive data in a data period do
    4: According to Corollary 1, calculate the lifetime $l^{(i-1)}$ at stage $S_{i-1}$, and the $i$-th batch of dead nodes region [$u_i$; $u_i$+£ "];
    5: Determine the traffic load and energy consumption of the sensor nodes at stage Si, i.e, [$p_1^{(i)},p_2^{(i)},\dots p_j^{(i)},\dots.p_n^{(i)}$] and [$e_1^{(i)},e_2^{(i)},\dots.e_j^{(i)},\dots.e_n^{(i)}$], according to Thm. 3 and 4
    6: $i = i + 1$;
7: end while
8: return the traffic load and energy consumption $p_j^{(i)}$ and $e_j^{(i)}$ (for each $i$ and $j$), and the network stage duration vector $l^{(i)}$ (for each $i$).
```

D. Analysis on Network Lifetime and Remaining Energy

Algorithm.1 can determine the entire network lifetime and the duration of each network stage. However, different WSN applications have different lifetime requirements.

Intuitively,lifetimerequirement can be described by the percentage of dead nodes in the network, which is also called death ratio.

Algorithm 2

Determining the emerging time and boundary of the energy hole.

Input: Network radius R, transmission radius r, node density of the network ρ, and other parameters.

Output: The energy hole boundary [d_{shole}; d_{ehole}] and emerging time t_h.

```
1: Run Alg. 1 until there is a continuous dead ring whosewidth d satisfies $d \geq r$;
2: The boundary of this dead region is the request[$d_{shole}$; $d_{ehole}$];
3: The lifetime at this network stage is the emerging time $t_h$;
4: return [$d_{shole}$; $d_{ehole}$] and $t_h$.
```

ENERGY HOLE AND NETWORK CHARACTERISTICS

A. Analysis on the Energy Hole Evolution

In this section, we investigate the temporal and spatial evolution of energy hole based on our analytical result. The traffic load and energy consumption of the sensor nodes and the network lifetime can be determined by Alg. 1, where the termination condition is that the sink cannot receive any data in a data period, which consists of two cases. One is all nodes die due to energy exhaustion. The other is some nodes still have remaining energy, but the sink is separated from the outer nodes after the formation of the energy hole. Thus, even if the network still has remaining energy, the network becomes useless and is also considered as disabled.

B. Observation on Network characteristics

The above analysis provides a comprehensive solution to determine the traffic load, energy consumption, and network lifetime, as well as the energy hole boundary for a WSN. Based on these analytical results, we conclude two observations on network characteristics as follows.

(1) If the sensor nodes are uniformly deployed in the network, the node density has no impact on the FNDT. According to our analytical results, FNDT depends on maximum nodal energy consumption at S_0, while nodal energy consumption is determined by the traffic load of sensor nodes. According to Thm. 1, traffic load is unrelated to node density, which proves that node density has little impact on traffic load. It also indicates that it is useless to improve the lifetime by increasing the node density.

(2) There exists an optimal transmission range r to maximize the network lifetime. According to Thm. 1, the transmission range of the sensor nodes r directly impacts the traffic load of sensor nodes, which determines the energy consumption and lifetime of the network. Therefore, we can set the optimal transmission range r for the sensor nodes to maximize the network lifetime. Since network lifetime can be estimated under a required death ratio i% by Corollary, and the options of r are limited, the optimal r can be found to maximize $l^{i}_{\%}$ with brute-force testing.

Here density control protocol is introduced for reducing the energy consumption and increase the network lifetime.It consists of that the node density increases means network coverage will be lesser and the node density decreases means network coverage will be higher.Due to the process,we can reduce the energy consumption and increase the lifetime of the sensor network. Density control in a wireless sensor network refers to the process of deciding which node is eligible to sleep (enter power-saving mode) after random deployment to conserve energy while retaining network coverage. A new density control protocol that needs no location information. It attempts to approach an optimal sensor selection pattern that demands the least number of working (awake) sensors.

IV. SIMULATION RESULTS

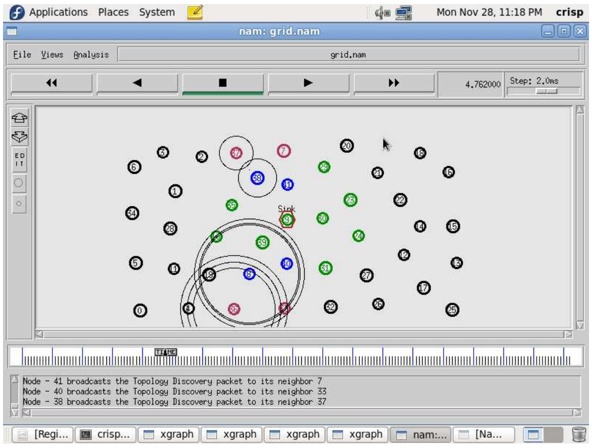
A. Experimental Results

In this section, we validate our analytic results by extensivesimulations in OMNET++. We perform our simulations in various scenarios where a large number of sensorsare deployed in a circular area with different network radii Rand transmission ranges r. The sink is located at the centreof the network. We summarize the main parameter settings in Table I, and the settings of the energy consumption model areadopted from [12]. All of simulations are based on a collision-free MAC protocol without data loss to be consistent with ournetwork model.

TABLE I
PARAMETER SETTINGS

Parameters	Values
Initial energy of a sensor node	E0 0.5 J
Duty cycle	10%
Duration of a data period Tr	10 s
Energy consumption rate for idel listeningEidle	0.88 mJ/s
Data transmissionrate B	512 Kb/s
Size of a data packet	400 bits

B. Result Analysis



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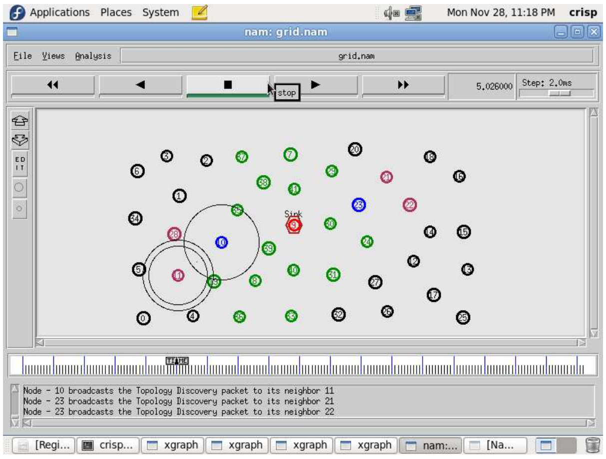
Node - 41 broadcasts the Topology Discovery packet to its neighbor 7
Node - 40 broadcasts the Topology Discovery packet to its neighbor 33
Node - 38 broadcasts the Topology Discovery packet to its neighbor 37
```

Node deployment



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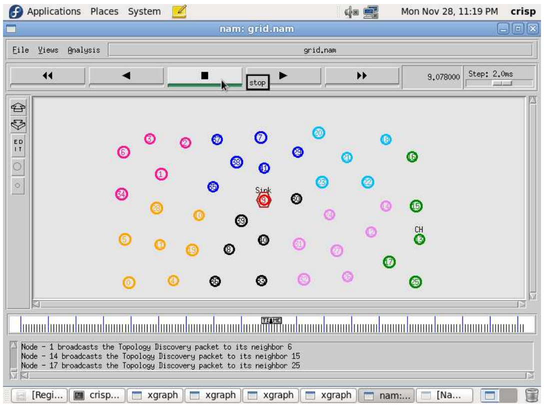
Node - 10 broadcasts the Topology Discovery packet to its neighbor 11
Node - 23 broadcasts the Topology Discovery packet to its neighbor 21
Node - 23 broadcasts the Topology Discovery packet to its neighbor 22
```

Broadcast message sending



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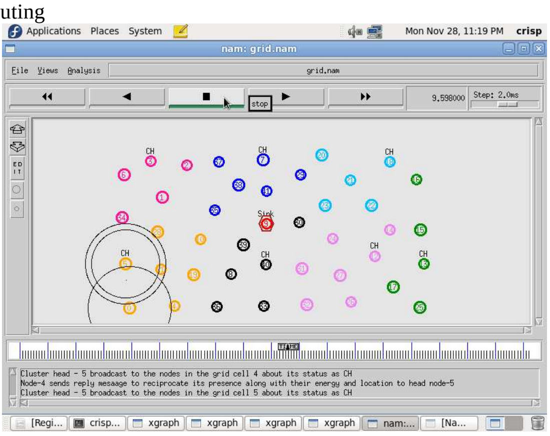
Node - 1 broadcasts the Topology Discovery packet to its neighbor 6
Node - 14 broadcasts the Topology Discovery packet to its neighbor 15
Node - 17 broadcasts the Topology Discovery packet to its neighbor 25
```

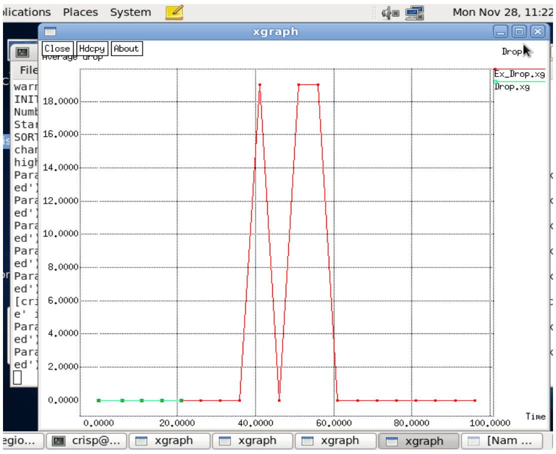
Routing



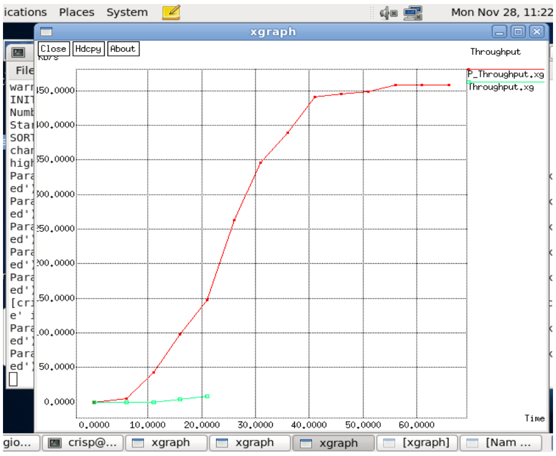
```
Cluster head - 5 broadcast to the nodes in the grid cell 4 about its status as CH
Node-4 sends reply mesaage to reciprocate its presence along with their energy and location to head node-5
Cluster head - 5 broadcast to the nodes in the grid cell 5 about its status as CH
```

Cluster head formation

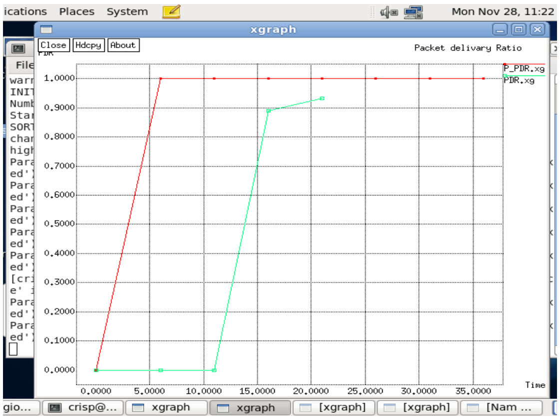
C. *Graph Analysis*



Packet drop



Throughput



Packet delivery ratio

Energy consumption

V. CONCLUSION

Thus we achieved a network lifetime, traffic load and energy consumption performance achieved through analytic model. With the analytic model, we have calculated the network lifetime under a given percentage of dead nodes, and analyzed the emerging time and location of energy hole, as well as its evolution process. Moreover, two network characteristics have been found based on our analytic results, which can be leveraged to guide the WSN design and optimization. The improved routing scheme based on our analytical results can efficiently balance the energy consumption and prolong the network lifetime.

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