Simulation Studies on Wireless Monitoring and Control of Water and Irrigation System using IEEE 802.15.4 MAC

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Abstract— **The purpose of this study is to analyze the simulation on wireless sensor network for low-cost wireless controlled and monitored irrigation solution using Zigbee/IEEE802.15.4. The Zigbee/IEEE 802.15.4 protocol proposes a flexible communication solution for Low-Rate Wireless Local Area Networks including sensor networks.**

In order to further increase the applicability in real world applications, minimizing energy consumption is one of the most critical issues. Therefore, accurate energy model is required for the evaluation of wireless sensor networks. In this paper, the energy consumption for wireless sensor network (WSN) node is analyzed. To estimate the lifetime of sensor node, the energy characteristics of sensor node are measured. Based on the proposed model, the estimated lifetime of a battery powered sensor node can be increased significantly. Most of the work has been done on NS-2 network simulator.

Therefore, the research model which has been used here is a simulation model. The results, performance measures of delivery ratio, energy consumption and lifetime analysis, of this work pave the way for an efficient dimensioning of an Zigbee/IEEE 802.15.4 cluster based mesh topology for monitoring and controlling of water and irrigation systems.

Key words: IEEE 802.15.4/Zigbee; Beacon mode; Super Frame structure; Cluster- based mesh.

I. INTRODUCTION

Implementation of automated irrigation system in countries like Ethiopia where its economy mainly depends on agriculture is critical for its sustainable development. The most significant advantage of automated irrigation system is that the right amount of water is supplied at the right time to the right depth in the soil for crops. Some of the drawbacks of manual based irrigation system are intense man power to operate and mismanaged water utilization. In addition, this regular manual-based operation system based on man power irrigation, leads either to excess or insufficient water allocation than a specific crop needs to its normal growth.

Mismanaged utilization of water in irrigation may impact the growth rate, seed quality and productivity of crops. This problem can be reduced if farmers can use automated irrigation system derived from the soil-water plant relationship [1], [2].

Therefore in this paper, it is proposed to develop an automated system that allows policy makers to apply the right amount of water at the right time to a given specific crop. It also reduces the intense man power and the amount of time he/she spent to operate the irrigation system manually in a given farm. In the proposed system, all the devices work automatically with the help of inputs received from the sensors installed for the purpose of monitoring real-time soil moisture content at the root zone in the soil. The entire process is controlled and monitored by programmable controller [3].

The approach and technology used in this paper, WSNs have been attracting much attention in the agriculture sector in the world. India, Australia, Turkey and Israel are among the countries which are using such technology for monitoring, storing and sharing sensed data [4]. The potential applications of WSNs are numerous few of them include; for cattle monitoring, for irrigation schedule, nuclear reactor control and security surveillance [5] .

The architecture of a WSN system comprises of a set of sensor nodes, a central sink units that can communicate the information received too with Actuators or valves [6]. With the modern developments in wireless networks regarding power requirements and cost, it has become possible to conceive an Automated Model for Precision Agriculture [1]. The process is that the conditions of the humidity, moisture, etc., in the crop field are transmitted to the central sink using Radio frequency wireless sensor modules and the information is further transmitted to the actuators or valves and it can take the necessary action thereupon by activating the Actuators or valves for irrigation or sprinkling pesticides for pest control. Thanks to recent technological improvements, new products using the WSNs are used to monitor some real world physical phenomena like pressure, temperature, humidity and vibration. WSNs consist of a set of small and low-power devices called sensor nodes. After being deployed on the area to monitor, these nodes are capable of local processing, communication and self-organization. In fact, they collect environmental information and work together to transmit the data to one or more collection points (sinks) in an autonomous manner [6].

However, in many scenarios, sensor nodes have to rely on a limited supply of energy (using batteries). Replacing these sources is usually not practicable, and simultaneously a WSN must operate at least for a given mission time. Hence, the lifetime prediction for WSNs becomes a major concern. For a reliable lifetime prediction, a complete energy consumption analysis is necessary [7]. Accordingly, it should consider the most important sources of energy consumption, namely transmitting and receiving data packets, listening to the channel, transmitting, receiving control packets (overheads) and receiving neighbors" packets (overhearing). In WSNs as their paradigm differs from traditional wireless networks. There is a need for low cost devices enabling large-scale networked embedded systems (as there can be hundreds or thousands of nodes scattered in large regions) and energy Requirements that impose low communication rates and ranges and low duty cycles.

Zigbee is considered to be a suitable network for sensing and control applications. Zigbee standard defined by the Zigbee Alliance [8] is a communication protocol for WSN. It provides mechanisms for network establishment, device communication and packets routing. Networks implementing this standard are low energy consumption and self-organized. The Zigbee standard is based on the IEEE 802.15.4 standard for the medium access control (MAC sub-layer) and for wireless transmissions and receptions (Physical layer).Three topologies are available in the Zigbee standard [8], i.e. mesh topology, star topology and Cluster-Tree topology. The beacon mode has been designed to work with a star topology. However, no mechanisms have been defined in the IEEE802.15.4 standard to enable the beacon mode using a Mesh or a Cluster-Tree topology.

In this paper, we are interested in the construction of a Beacon Cluster-based mesh topology, i.e., constructing a Cluster-based mesh topology using the beacon mode.

II. EXISTING PROBLEMS OF THE STANDARD

The joint efforts of the IEEE 802.15.4 Task Group [9] and the Zigbee Alliance have ended up with the specification of a standard protocol stack for Low-Rate Wireless Personal Area Networks (LR-WPANs), an enabling technology for WSNs [5]. Therefore, this work aims at using the IEEE 802.15.4 and Zigbee Protocols as a baseline which leads to easier, faster and widespread development, deployment and adoption.

Currently there is insufficient data comparing beacon and non-beacon network configurations as well as beacon frame collision problem in cluster-tree Zigbee WPANs has been addressed as Request for Comments in the Task Group 15.4b [11]. In this paper, we tried to tackle the different types of beacon frame collision conflicts identified by the Task Group 15.4b in Reference [11].

This knowledge is important when setting up a Zigbee cluster-based mesh network to prevent excess power consumption and reduced battery life especially in a real time monitoring application [10].

This paper presents the Zigbee standard, a distributed mechanism that enables mesh networking over the IEEE802.15.4 beacon mode. Results show that the proposed strategy enables collision free and energy efficient multipath mesh networking in a distributed manner.

Moreover, based on performance measures of delivery ratio and energy consumption analysis, an analytical model used to predict the lifetime of IEEE 802.15.4 WSNs. The model also aims to give a realistic prediction of the lifetime in order to predict the network availability and reliability.

III. PROPOSED SYSTEM DESIGN

Concerning on the aforementioned problems motivated how to tackle the problems and planned to design the system that will lead to conservation of water and improvement in energy efficiency.

In order to offer to network architects more flexibility in designing WSN, we present a Beacon Cluster-based topology construction approach. Our approach is different from what was proposed until now. We summarize our contribution in two points:

1. Despite the size of the networks, the construction of a beacon Cluster-based mesh topology is always possible.

2. Scheduling was done Based on SuperFrames parameters and TDMA algorithm.

Indeed, in this paper, we present our best approach method that exploits wireless receivers capability in dealing with multipath to retrieve transmitted data in order to avoid scheduling problems.

PLACEMENT OF SENSOR NODES

Optimum placement whether dynamically or statically has equal advantages of maximizing network lifetime, improving network efficiency, reduce number of sensors to be used and increase the coverage thereby improving data collection which in turn would have a direct impact on the level of precision in our precision irrigation. While many published papers aim at maximizing the lifetime our aim is to maximize utilization efficiency and coverage for optimum data collection.

SELECTION OF CLUSTER HEADS AND MULTI-HOP ROUTING SET-UP

In our technique, we consider the device type factor and the energy factor to choose cluster heads and relay nodes. The static sink node is located in the edge of the rectangle sensor network, and sensor nodes are deterministically deployed in this rectangle area. Each sensor node is located at equal distance to CH sensor nodes forming a circular cluster based cluster and having different distance to the static sink node. Each sensor node will set up a table to store the residual energy, CH the will set up a table to store distance and the relative node ID and the information of the distance will be kept in the sink node. The CH nodes will be able to determine the maximum and the minimum distance to the sink node.

We found that sensors should be placed more uniformly as their sensing range or the path loss exponent increases, and more sensors should be deployed as the event arrival rate increases or the power consumption decreases. Sensors monitor the events of interest and send them to the CH node where the sink node can access it. Sensor placement is according to their distance from the CH node.

We propose an approach that allows forming Cluster-based mesh networks topology without regard to the density of the network. Moreover, our approach is based on Superframes and also a Beacon frames transmission scheduling. The design of the proposed topology is given by the figure below.

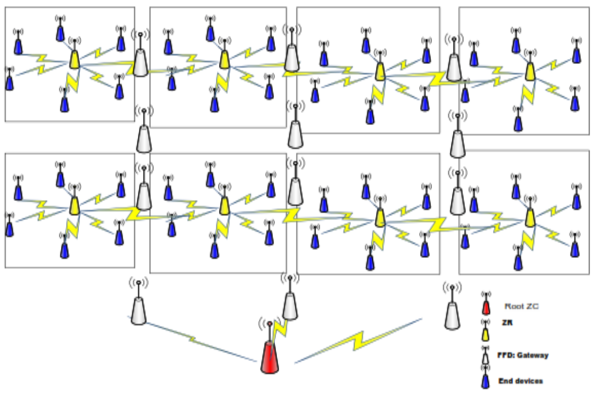

Figure 1. Proposed cluster-based mesh topology

We proposed an approach of implementing multiple Cluster-based mesh topology it has been assumed that the nodes are scattered in some area, it might be some harsh environment or some open field for the measurement of an environmental condition, it has to be noted that since Zigbee protocol is to be used therefore there must be at-least one full function device known a PAN-coordinator , which can synchronize the entire network devices with its beacon generated after every regular interval of time for synchronization of the node and there activity , during the synchronization process the devices only tends to get synchronize with the full function coordinator instead of accepting any kind of data , once they get synchronized with the pan-coordinator then the transfer of data will occur immediately between node to coordinator or sink to coordinator, but since we are dealing with a harsh environment, therefore if there is any obstacle between the devices then the communication between the devices not only get distracted but also sometime the devices lost their synchronization with the coordinator or also the number of hops get increased as shown in above ,again in this figure there are special devices indicated by pink square rounded (relay nodes) which are assumed in the worst case that they have totally lost their synchronization from the pan-coordinator and get disconnected from the network, in-order to overcome this situation the topology is divided into quadrants with different coordinators , this reduces the number hops in the topology in case of obstacles in between and also reduce the risk of devices to get disconnected from the network.

COMMUNICATION OVERVIEW

The MAC protocol in IEEE 802.15.4 can operate on both beacon enabled and non- beacon modes. In the non-beacon mode, a protocol is a simple CSMA-CA. This requires a constant reception of possible incoming data. The power saving features that are critical in WSN applications are provided by the beacon-enabled mode. Hence, we concentrate on the beacon-enabled mode from now on.

In the beacon-enabled mode, all communications are performed in a superframe structure. A superframe is bounded by periodically transmitted beacon frames, which

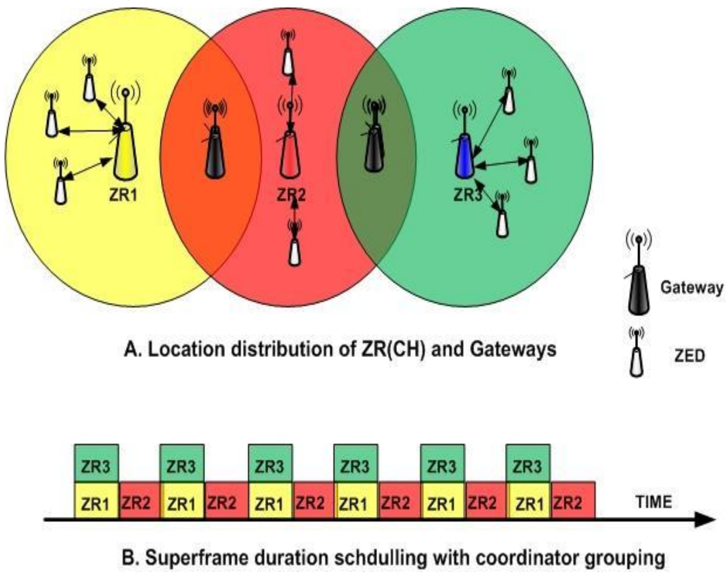

Figure 2. communications performed in a superframe structure.

allow nodes to synchronize to the network. An active part of a superframe is divided into 16 contiguous time slots that form three parts: the beacon, Contention Access Period (CAP) and Contention-Free Period (CFP). At the end of the superframe is an inactive period, when nodes may enter to a power saving mode.

In this paper, we propose IEEE 802.15.4 MAC (Zigbee on top of it) with an aim to enhance the performance and energy consumption in order to support real-time communications. These enhancements out of a provision for multiple and successive retransmission attempts for a failed transmission of a data frame.

This is in contrast to the idealistic cluster based mesh specification, where a failed frame gets a delayed retransmission attempt and by that time the information may become obsolete. We simulate all proposed schemes as well as the idealistic cluster based mesh and compare their performance and energy consumption to show that significant performance gains are achievable by our proposed changes.

SIMULATION SCENARIO

In this section, we will explain the design model for the idealized and the proposed Cluster based mesh topology using scenario1 and scenario2.

Scenario 1: idealized Cluster based mesh topology

This scenario was modeled with four coordinators, and a PAN-coordinator a propagation model of two-ray ground reflection and Cluster based mesh topology. In simulation it has been assumed that there are obstacles in the network and the signal propagation chosen for this scenario is a two ray ground reflection model as described earlier in section, below (Figure 3) shows the simulating scenario.

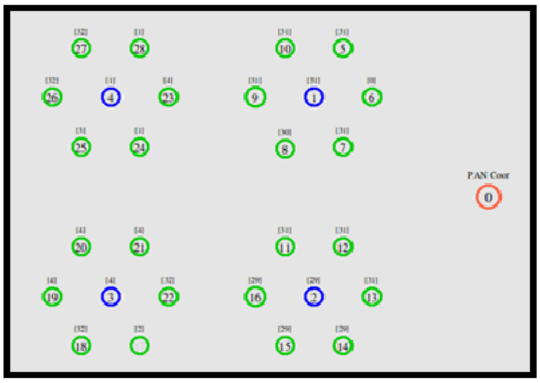

Figure 3. Represents the proposed Cluster based mesh topology scenario

Scenario 2: proposed Cluster based mesh topology

This scenario was modeled with (4 coordinators, multiple relay nodes and PANcoordinator propagation model: two-ray ground reflection, topology, and cluster – based mesh network).

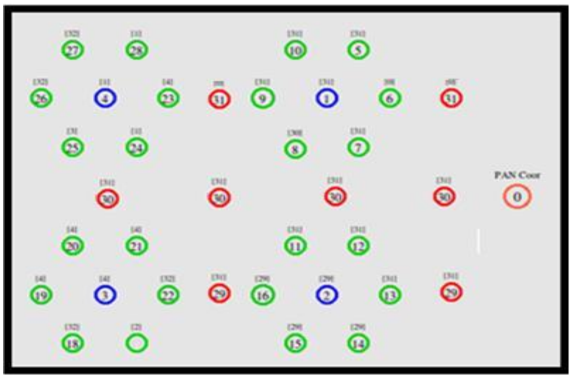

Figure 4. Represents the proposed Cluster based mesh topology scenario

This scenario with relay nodes (intermediate nodes) model caused deviation and minimizes multipath fading effect in the radio signals, which makes simulation near to real-world implementation, it has only one pan-coordinator to synchronize the devices, which means the environment is assumed to be very harsh for the data transfer and many obstacles will arrive in between the nodes. The above figure is showing the proposed model on sensor nodes, analytical details will be discussed later.

IV. SIMULATION RESULTS AND DISCUSSIONS

The simulator was configured as Beacon Mode with the parameters listed in Table below and then executed with the tcl program. This produced the following results which are discussed in the following sections.

SIMULATOR CONFIGURATION PARAMETERS

Parameter	Value
Beacon order	6-10
Superframe order	3-5
Time period between packets	30, 60, 100, 200 and 1000 seconds
Packet size	60 bytes
Simulation time	1000 seconds
MAC	IEEE802.15.4
RP	AODV
Antenna	Omnidirectional
Number of nodes	29 and 33
Energy capacity	9720 joules
Traffic direction	Bidirectional
Transmit current consumption	17.4 mA
Receive current consumption	18.8 mA
Sleep power consumption	20nA
Number of simulations	10

This section contains the battery consumptions and delivery ratio, of the two scenarios, results for beacon mode operation at data rates 30, 60, 100, 200 and 1000 seconds/packet are illustrated in the figures below, based on the above list of parameters.

IDEALIZED CLUSTER-BASED MESH

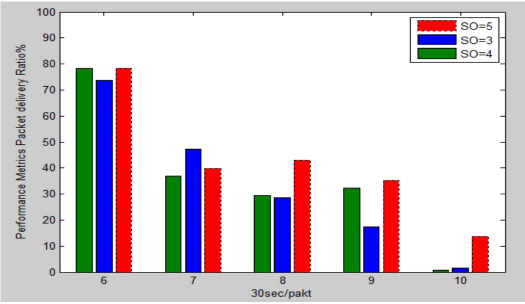

Figure 5.Average delivery ratio of nodes at data rate 30 seconds/packet at SO 3-5

Figure 5 depicts the delivery ratio of the network under data rate 30 seconds/packet. When using a receiver capable of detecting packets as low as -97dBm, Beacon order of 6 and superframe orders 3 to 5, maintain a delivery ratio of over 80%. However, exponentially decreases for higher BO. Thus as can be seen from the graphs, nearly all packets are delivered in applications maintain low BO.

Energy Analysis indicated in Figure 6. The energy performance indicates that as long as the network is free from congestion for 30 seconds/packet, the gradual decrease in the delivery ratio of the network would in turn increase the wake time of the transceiver and hence the power consumption is linearly increasing.

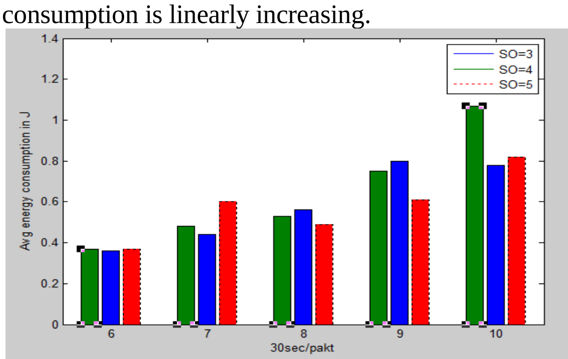

Figure 6. Average energy consumption of nodes at data rate 30 seconds/packet at SO3-5

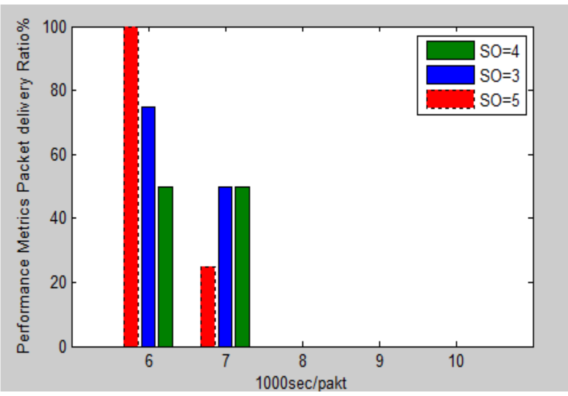

Figure 7. Average delivery ratio of nodes at data rate 1000 seconds/packet at SO 3-5

Figure 8, depicts the delivery ratio of the network under data rate 100 seconds/packet.

When using a receiver capable of detecting packets as low as -97dBm , Beacon order of 6 and superframe orders 3 to 5 , maintain a delivery ratio closer to 100%. However, unexpectedly decreases to 0% for higher BO of 8 and above. Thus as can be seen from

the graphs, nearly all packets are delivered in applications maintain having BO <=7.

Energy Analysis indicated in Figure 8. The energy performance indicates that as long as the network is free from congestion for 1000 seconds/packet, the gradual decrease in the delivery ratio of the network would in turn increase the wake time of the transceiver and hence the power consumption is unpredictably fluctuating.

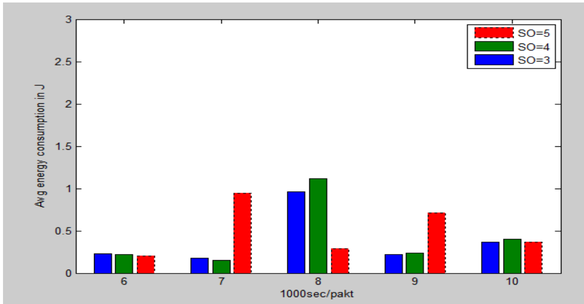

Figure 9.Average energy consumption of nodes at data rate 1000seconds/packet at SO 3-5

PROPOSED CLUSTER-BASED MESH

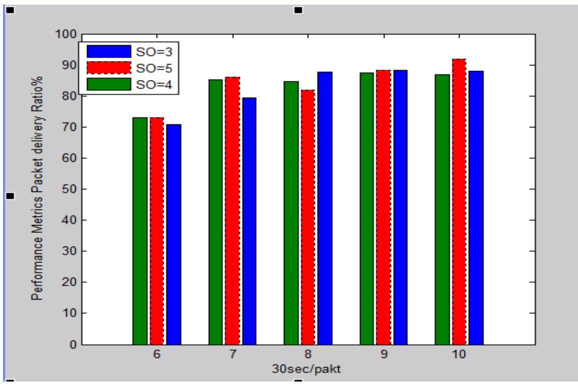

Figure 10.Average delivery ratio of nodes at data rate 30 seconds/packet at SO 3-5

Figure 9, depicts the delivery ratio of the network under data rate 30 seconds/packet.

When using a receiver capable of detecting packets as low as -97dBm , Beacon order of 6 and superframe orders 3 to 5 , maintain a delivery ratio closer to 70%. However, exponentially increases for higher BO. Thus as can be seen from the graphs, nearly all packets are delivered in applications maintain higher BO.

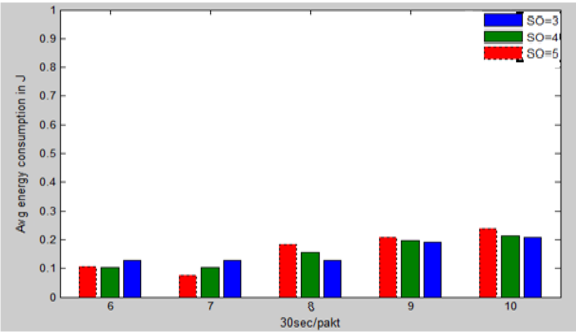

Figure 11. Average energy consumption of nodes at data rate 30 seconds/packet at SO 3-5

Energy Analysis indicated in Figure 10. The energy performance indicates that as long as the network is free from congestion for 30 seconds/packet, the gradual increases in the delivery ratio of the network would in turn decreases the wake time of the transceiver.

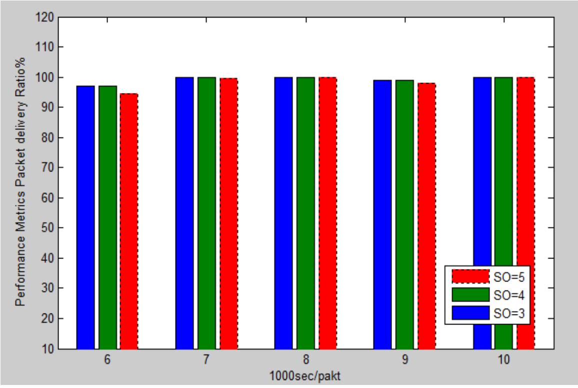

Figure 12.Average delivery ratio of nodes at data rate 1000 seconds/packet at SO 3-5

Figure 11 depicts the delivery ratio of the network under data rate 1000 seconds/packet.

When using a receiver capable of detecting packets as low as -97dBm, Beacon order of 6 and above and superframe orders 3 to 5, maintain a constant delivery ratio of 90% for all ranges of BO.

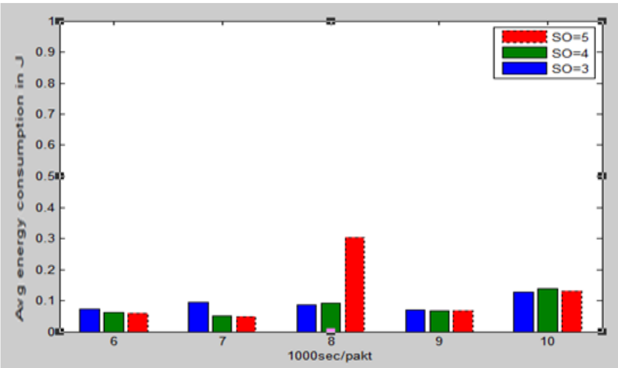

Figure 13. Average energy consumption of nodes at data rate 1000 seconds/packet at SO3-5

Energy Analysis indicated in Figure 12. The energy performance indicates that as long as the network is free from congestion for 1000 seconds/packet, the gradual increases in the delivery ratio of the network would in turn decreases the wake time of the transceiver and hence the power consumption of nodes reduced by half than the responding idealized and for higher beacon orders it is insignificantly increasing.

Generally the results for idealized cluster-based Mesh were unsatisfactory and indicate serious problems with the scenario or its configuration. In beacon mode, packet delivery ratio was only just acceptable at lower beacon orders and the delivery ratio was lowest at the lowest data rate which is the opposite of what was expected. Beacon order 10 shows a delivery ratio of almost 0 for all but one data rate.

In proposed cluster based mesh, the results were more as expected with the delivery ratio improving as the data rate decreases and energy consumption decreases too. Moreover, delivery ratio was still looks good and even at the fastest data rate of 30 seconds per packet it was still expected to have a delivery ratio above 80 %.

Based on the above results, it is assumed that the lower than expected energy consumption results are due to excessively minimized collisions, dropped packets and retransmissions. The improved delivery ratio results, especially at higher beacon orders also suggest this.

V. CONCLUSIONS

This work has clearly shown that in single sink IEEE 802.15.4/Zigbee wireless networks applied to monitoring and control of water and irrigation systems, beacon mode gives the longest battery life (lowest power consumption) and the best delivery ratio at all tested data rates in computer simulations.

From the results presented in this paper, IEEE 802.15.4 in beacon mode results in significantly lower power consumption (higher battery life) and a good delivery ratio.

Moreover, it is likely that in applications where there is bidirectional traffic, the synchronization provided in beacon mode could be an advantage and could result in
Further simulations could be undertaken with mobile nodes and a time critical network to investigate the effect on power consumption and delivery ratio.

The simulations and scenarios presented in this work could be unidirectional with unidirectional traffic, for example, traffic from only the end devices to the coordinator.

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