

# Energy efficient On-Demand Addressing for Wireless Sensor Networks

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**Abstract**—Conserving of battery power is a critical requirement in WSNs. Past studies have shown that the transeiving process consumes more energy than the internal processing. This work focuses on eliminating overhead messages used for address allocation by employing multiple base-stations. In this context we explore address allocation without Duplicate Address Detection (DAD). We present an alternative approach to Duplicate address detection using the sink as an address pool to maintain and systematize available addresses. Experimental results show that this approach eliminates overhead messages generated by DAD; resulting in energy savings when used in conjunction with an on-demand address allocation mechanism.

*Keywords* – *Sensor Networks, Address Allocation, Duplicate Address Detection, on-demand address allocation, Address Auto Configuration*

## I. INTRODUCTION

In modern era of computer networks Wireless Sensor Networks (WSNs) have come into prominence because they have the potential to revolutionize various aspects of our lives [1]. WSNs consist of a large number of battery-powered devices called sensor nodes. These nodes are equipped with one or more sensing devices. These sensing devices are capable of collecting environmental data or monitoring movement of an object [2]. WSNs can be mobile, or fixed to a geographic location [3], but their mobility is limited as compared to mobile ad-hoc networks [4]. Contrary to more traditional computer networks, WSNs are subject to a unique set of resource constraints such as limited battery power, limited computational power, inadequate communication bandwidth, limited memory, error-prone transmissions, limited storage and restricted to basic input and output mechanisms.

A sensor node's life time is limited to the life time of its battery. Nodes mainly drain their energy during the communication process (which involves transmitting and receiving data) rather than in processing data. Past studies have shown,

transmitting a bit 100 meters by radio consumes the same energy as executing 3000 instructions [2]. It should therefore be possible to increase the lifetime of a node by eliminating overhead messages and reducing the number of bits in packet transmission.

Current address assignment mechanisms generate addresses with a large address space leading to additional transmission bits. They also employ a considerable number of control messages which results in significant communication overhead. The main predicament in address assignment is allocating unique addresses to every node in the network. To route packets accurately all the nodes should have a unique network address. In current address allocation methods uniqueness is being guaranteed by executing Duplicate Address Detection (DAD) [2, 5, 6]. However its main weakness is that DAD is based on packet flooding which results in a large number of redundant messages.

In this paper we propose an energy efficient address allocation mechanism for WSNs. The study primarily focuses on exploring on-demand address allocation without employing DAD and the utilization of multiple base-stations (BS). The study explores the viability of using multiple BSs for nodes to save more energy. By performing simulation studies we evaluate the proposed method from the viewpoint of the number of control messages for address allocation. The study proposes a DADless Distributed Base-Station (DDBS) architecture for WSN.

The rest of the paper is organized as follows. In section II we discuss related work and their problems. Section III describes the problem motivation. In section IV we explain the proposed scheme. Simulation results and evaluation are provided in section V to validate the model. In section VI we conclude this paper with a summary of our findings and suggestions for future work.

## II. RELATED WORK

Hardware based identification would be an effortless approach which leads to globally unique IDs. For example IPv6 enables the creation of an address from a 48-bit IEEE MAC address, which is

intended to be globally unique [7]. However the work presented in [8] claims drawbacks as there are known instances of multiple network cards from the same vendor having the same MAC address, unregistered MAC addresses and most adapters allowing users to change their MAC address to random values. Another issue is that hardware based addressing raises the argument of location-privacy. Further, applying a 48-bit address creates a disproportionate communication overhead as typically the packet size of a sensor network is as small as 16-bytes [9]. The small packet size makes the 48bit address highly unviable in terms of message overhead.

The Mobile Ad-Hoc Network (MANET) working group of IETF proposes multiple rounds of DAD, since usage of DAD once cannot guarantee that all nodes have been reached [5]. Such an approach results in a large number of DAD related control messages.

The MANETconf proposes a distributed Dynamic Host Configuration Protocol (DHCP) to configure MANETs [10]. In this approach, an existing node offers a candidate IP address to a newly arrived node and the assignment of an address must be confirmed by all the nodes in the network. The address allocation to a newly arrived node repeats until all nodes agree with the new address assignment. The confirmation process uses a large number of control messages which causes a considerable overhead.

The work explained in [2] proposes a method which allocates a temporary address to a sensor node which detects an event in an on-demand fashion. Comparing to other approaches such as [5, 10, 11], the proposed on-demand allocation reduces the required address space by only allocating addresses when required. It is argued that allocating unique addresses to all the nodes waste the address range resulting in long addresses that causes more bits to be transmitted. For example allocating addresses to 300 nodes may require  $2^9$  bits in the address range but if only an average of 5 nodes generate events at a given time, it only requires  $2^3$  bits in the address range. The study in [2] also states that the allocated addresses can be released after completion of the communication process. However the main drawback of [2] is that it uses DAD to maintain the uniqueness of addresses. As a result it suffers from the high overheads incurred by other DAD based address allocation mechanisms.

### III. PROBLEM MOTIVATION

There are two main motivational factors. The first one is the large number of control messages generated as a result of DAD. The second key factor is the energy wastage in long distance communications with a single BS.

Distant nodes do not communicate directly with each other. They communicate via the multi-hop technique. A routing mechanism is responsible for selecting the path for a node to communicate with

its endpoint. A DAD request is typically flooded and may use the energy of multiple nodes in the network to reach a destination. If a duplicate address is detected, it drains the energy of the intermediate nodes in the communication path to send a response message to the destination. The large amount of overheads in DAD, accentuates the necessity of a more efficient address allocation method.

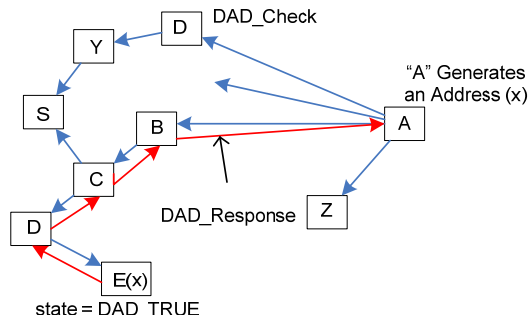


Figure 1. Duplicate Address Detection

Figure 1 illustrates an example of DAD. When a node requests a random address or selects an address by itself, it needs to verify its uniqueness. The node cannot assign the selected address as its network address without knowing its distinctiveness. In this scenario node 'A' inserts its selected address 'X' and its location details in a DAD\_Check packet and floods the network with the DAD\_Check. Each node receives the DAD\_Check compares its network address with the senders selected address. Then the received node passes it to other nodes in the network. If a similar address is detected, that node creates a DAD\_Response packet and sends it to the originator of the DAD\_Check packet. Node 'A' waits for a pre-defined time period to receive a DAD\_Response message. If 'A' receives a response packet within that time period, 'A' has to select another address and repeat the DAD process. This repeats until the uniqueness is verified within the network. If the node fails receive a DAD\_Response message within its timeout period it decides that the selected address is available and allocates the selected address as its network address. The main factors that contribute to energy wastage in DAD are,

- The node that needs a new address redundantly spends energy to generate a DAD\_Check.
- Nodes that receive the DAD\_Check waste their energy to process it and distribute it to other nodes.
- If similar address is detected, the detected node creates a response packet and transmits it to the originator of the DAD\_Check.
- Multi-hop communication wastes energy of the nodes along the communication path by transmitting the DAD\_Response message until it reaches the intended recipient.

- The entire process repeats until the assigned address is unique within the network.
- Energy wastage due to long distance communication will be discussed under the multiple DDBS model.

#### IV. PROPOSED SCHEME

The proposed DDBS method employs on-demand address allocation using a centralized architecture.

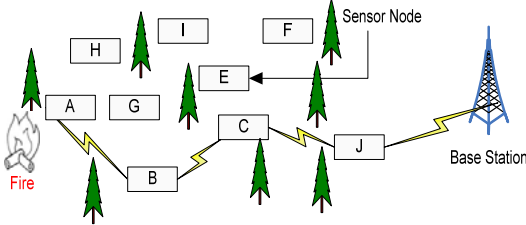


Figure 2. On-demand addressing for WSN.

In the proposed method address allocation is done by BSs acting as centralized servers. An event would trigger, the node to send an address request to the BS. The BS maintains an address allocation table and sends the first available address to the requested node (Figure 3). Below (b) and (c) of Figure 4 illustrates the before and after states of the address allocation table. Address 101.04 is the first available address before BS receives the address request from the node 'A'. After sending it to the requested node, table updates address 101.04's state as allocated. This avoids the same address being allocated to any other node in the network. The requested node does not have to be concerned about address duplication since it is controlled by the BS. This technique eliminates DAD and packet misrouting due to identical addresses.

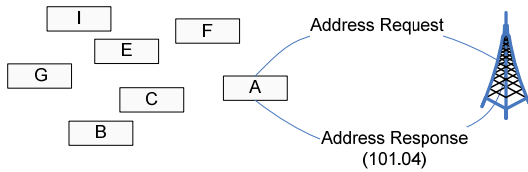


Figure 3. Centralized address allocation

101.04	Available	101.04	Allocated
100.30	Available	100.30	Available
101.25	Allocated	101.25	Allocated
101.40	Available	101.40	Available
100.50	Allocated	100.50	Allocated

(b) (c)

Figure 4. Address allocation Table

##### A. On-demand address allocation with DDBS

This work proposes a model based on the above concept to increase the energy efficiency of WSNs.

We argue that distant nodes need to communicate through a higher number of nodes to contact the BS than nodes located nearby. As a result, distant nodes use more control messages than nearby nodes resulting in higher transmission overheads. Positioning multiple BSs randomly or systematically would provide a preference for the nodes to select the closest BS and reduce unnecessary control messages. The utilization of multiple BSs provides two key directions.

1. Reduce the communication distance by selecting the closest BS.
2. Organize the address range more efficiently by dividing the network into sub networks.

This mechanism can be illustrated as a distributed technique, because the network is not controlled by a single entity. All the BSs send their data to a main monitoring station. Figure 5 illustrates the concept of employing multiple BSs. In Figure 2 node 'A' communicates via nodes B, C and J to reach the BS, but in Figure 5 'A' has a preference and it only needs to go through H to reach the closest BS.

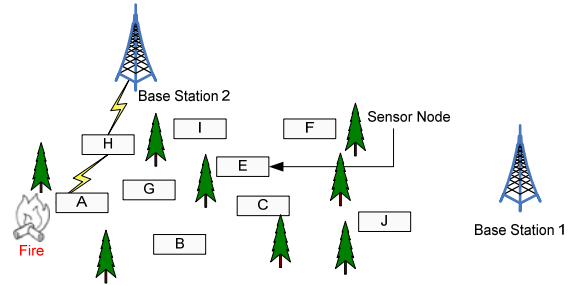


Figure 5. Distributed base-station address allocation

This technique is more suitable for large sensor networks where distant nodes may have to communicate through a large number of intermediate nodes to reach the BS. Further, in such a scenario, 'hot spots' occur where all traffic to the BS is routed through a subset of nodes close to the BS. This can result in the BS becoming unreachable if these set of critical nodes die or get congested.

To enhance the efficiency of DDBS, the pool of addresses is maintained in a distributed manner as proposed. In this approach, the entire network is divided into sub networks based on the positioning of BSs. Nodes discover the closest BS by analysing BSs' location information (all nodes are location aware). Figure 6 illustrates this point by utilizing two BSs. Nodes A, H, I, G and B have decided BS 2 as their closest and nodes E, C, F, J and C have preferred BS1. Nodes situated in similar distance select either one as their centralized server. A node's address need only be unique within its own sub network; further reducing the required size of the address space.

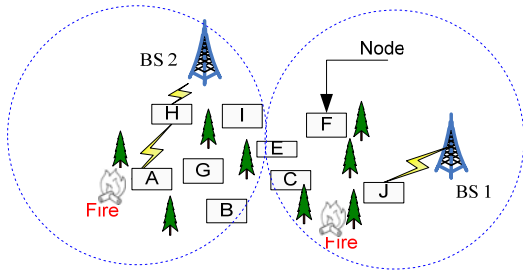


Figure 6. Address range maintenance via DADless Distributed Base-Station model

Each sub network can operate independently if the sensor network application does not involve interaction of nodes among neighboring groups. As a result BSs can use the same address range without conflicting addresses. As a result, network addresses only have to be unique within a sub network. There can be duplicate network addresses within the same network as long as they do not fall under one subnet. This process increases the reuse of network addresses and reduces the number of bits in an address by shortening the address space.

## V. EXPERIMENTS

Simulations were conducted using OPNET modeller. The first simulation was performed to calculate the energy wastage generated as a result of DAD. Subsequently centralised address allocation was implemented using the proposed DDBS model. 300 nodes were arranged over a terrain of 700m<sup>2</sup>. Simulations were executed by varying the number of BSs from one to five. All the BSs were positioned randomly. Once the network boots-up all the BSs broadcast their network addresses and location information to the network. Nodes fetch those broadcast packets. After receiving broadcast packets from each BS, nodes calculate the distance from their position to the BSs to determine the closest one. Nodes calculate the distance ( $d$ ) using location coordinates of BSs and coordinates of themselves.

$$d = \sqrt{((\text{node X} - \text{sink X})^2 + (\text{node Y} - \text{sink Y})^2)} \quad (1)$$

The simulation was programmed to generate events randomly for nodes to send address request packets (ARQ). Nodes direct the address request packet to the selected BS by considering their positioning in the network. The network uses multi-hop communication to transmit packets to the intended recipient. The ARQ contains the distance from the sender to the recipient. Each Intermediate node compares this distance with its own distance to the intended recipient. If the intermediate node's distance is greater than the sender's distance, then the intermediate node simply discards the packet assuming it is located further away from the recipient than the sender. The first model was designed to calculate the total number ( $T$ ) of messages in the network generated with a single BS.

$$T = \sum \text{ARQ} + \sum \text{ARP} + \sum \text{ARL} + \sum \text{BM} + \sum \text{ACK} \quad (2)$$

Where ARP is the address response, ARL is the address release message, BM is the broadcast message and ACK represents acknowledgements.

The second model was executed with the exact settings but varying the number of BSs. Multiple simulation runs were completed for both scenarios and the results presented are averaged over all runs.

Figure 7 evaluates the total number of messages generated by DAD based and DDBS networks. The proposed method shows a clear decrease in the total number of messages. This graph gives a general idea of communication overhead generated in the DAD based model. Our assessment is that the total number of messages can be reduced by reducing the communication distance and elimination of redundant control messages. This principle applies to networks which employ multi-hop communication.

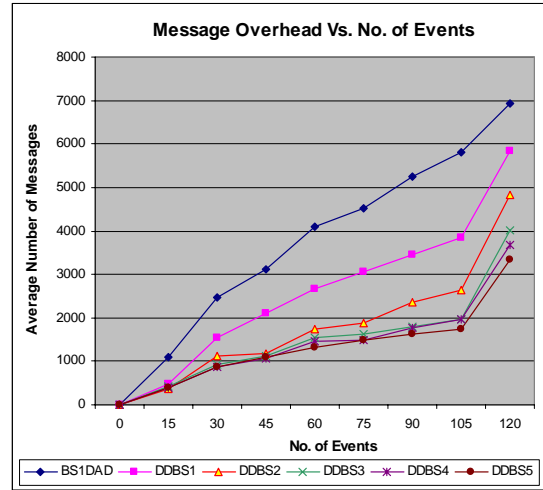


Figure 7. Comparison of total number of messages

The question that arises at this point is, whether the total number messages is inversely proportional to the number of base-stations.

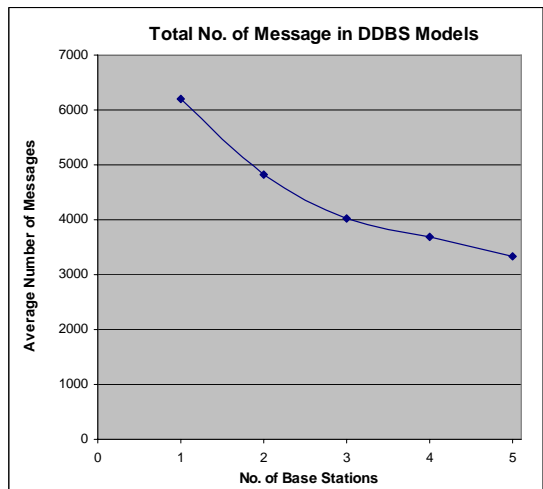


Figure 8. Summary of total number of messages

Figure 8 shows the fall of total number of messages with the increasing number of BSs. There is a clear drop from single BS to two BSs model. However the drop in the total number of messages from one level to another reduces gradually. This is attributed to the higher number of broadcast messages generated by each BS.

## VI. ENERGY CONSUMPTION

For a wireless sensor network the energy consumed by a node consists of the energy consumed by sensing, transmitting, receiving, listening for packets, internal processing, discarding a packet [12, 13] and even in its sleep state. The Energy consumption  $E$  is measured in millijoules per second or milliwatts.

As presented in [12] calculating the total power usage can be done by multiplying  $E$  by the node life span  $l$ . In this scenario we primarily focus on the energy consumption as a result of transmission and receiving messages. According to [1, 6, 9, 12] the total energy consumption ( $E$ ) can be presented as,

$$E = E_{rx} + E_{tx} + E_{listen} + E_d + E_{sleep} \quad (3)$$

Energy consumed during the transmission ( $E_{tx}$ ) = energy wasted by switching to transmitting mode ( $T_x$ )  $\times$  data rate in bits per packet ( $r$ ) + energy wasted by the transmit amplifier ( $E_{amp}$ )  $\times$  data rate in bits per packet ( $r$ )  $\times$  distance<sup>2</sup> ( $d$ )

$$E_{tx} = T_x \times r + E_{amp} \times r \times d^2 \quad (4)$$

Energy consumed during the receiving ( $E_{rcv}$ ) = Energy wasted by switching to receiving mode ( $R_x$ )  $\times$  data rate in bits per packet ( $r$ )

$$E_{rcv} = R_x \times r \quad (5)$$

The total energy consumption ( $E_T$ ) due to communication can be represented as,

$$E_T = \sum (E_{tx} + E_{rcv}) \times T_{msg} \quad (6)$$

Where  $T_{msg}$  is the total number of messages used during the communication process.

## VII. CONCLUSION AND FUTURE DIRECTIONS

In this paper we have presented an energy efficient address allocation mechanism using distributed BSs. Our experiment results demonstrate that the total number of messages in a wireless sensor network can be reduced significantly by employing multiple BSs. It is also evident that the increase of BSs is not directly proportional to the drop of messages. The number of BSs in a network may vary under different circumstances. Depending on the cost of base stations and similar factors such as geographical limitations, it may not be practical to always utilize multiple BSs in order to reduce the number of control messages. Employment of DDBS varies vastly on the nature of the application. The DDBS model is well suited for large networks. For

a small network, broadcast communication cost of multiple BSs may even be counter-productive.

This study has assumed that nodes in different sub-networks do not communicate with each other. In an application where nodes in different subnets require communicating, they will not be able to use the same address space.

The study only discusses the proposed model on a fixed WSN. Our future work will focus on making the model applicable to a mobile network. Our future work will also involve discovering the optimal number of BSs for a given WSN and the accurate positioning of these multiple BSs for maximum benefit (energy-efficiency).

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