An Addressing Scheme for a Network of Wireless Sensors and Mobile Clients for Cluster-9

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Abstract

One of the major constraints plaguing Wireless Sensor Networks (WSN) is its inherent limitation on the power supply available to the sensor. We propose a method of reducing the amount of header bits required for the transmission of messages within a WSN, bearing in mind that the sensors' radio for the most part is the most power hungry component of the sensor. This paper introduces the concept of using mobile equipments that communicate with sensor located anywhere on the network to add pervasive computing capabilities. The use of mobile equipment requires additional addresses for the mobile equipment as well as requiring the implementation of routing techniques. Our model uses an efficient transmission path and reusability based sensor-addressing scheme with minimum increase in the processing capabilities required by the sensors to attain our objective. The saving in terms of the percentage of overhead bits was found to proportionally increase with the number of sensors and clusters within the WSN.

Keywords: *Wireless Sensor Networks (WSN), Mobile Equipments (ME), Super Nodes (SN)*

1 INTRODUCTION

Wireless sensor technology [1, 2] is a technology that has been recently deployed for various purposes. Wireless sensors are typically placed in the environment and has been used for seabird habitat monitoring [3], inventory tracking [4], and event detection for the military [5] . Wireless sensors can also be placed on objects, for example on a human and objects in the environment to detect the location of the humans based on the proximity to an object [6].

In a network, wireless sensors talk only to each other or to a base station. This paper introduces the notion of mobile equipments communicating with sensors directly. The use of mobile equipment that communicates directly with sensor allows real-time pervasive applications. Imagine sensors that can detect real time traffic congestions placed around the city, and drivers with mobile equipments that shows where those congestions are. Another possible application would be using sensors to detect human movement. Soldiers with mobile equipment can determine where the enemy movements are.

Even with the advancements in the field of Wireless Sensor Networks (WSN), one of the major constraints of a WSN is its inherent dependence on the sensors available power supply. Efficient usage of the limited power supply at each sensor node would go a long way in reducing the overall cost of the WSN and consequently increase its potential applications. In general, the most power hungry component of a sensor is found to be on the radio transmitter, in particular.

In this paper we create a scheme to reduce the number of bits transmitted with the aim of reducing the power consumption of the sensor. The Cluster-9 addressing scheme is a two-fold approach aimed at first of all reducing the number of bits transmitted as part of the header. This is achieved by reducing the number of bits required to identify the source and destination address of the sensor or mobile equipment as well as the address of the next hop along the transmission path. Secondly, we minimize the number of sensors that are required to relay the message from source to destination by embedding routing information in the addressing scheme. This is achieved by the addition of only 4 bits to the header.

The following section describes some of the related work in WSN and also a brief description of the general concepts behind a WSN. The assumptions and problem statement is described in greater detail in Section 3.1. In Section 4, we delve into the workings and the setup of the network and also describe the addressing scheme used. This is followed by the Evaluation and the conclusion in Section 5 and 6 respectively.

2 RELATED WORK

A wireless sensor will typically only have a small energy capacity. One hot topic of research is disseminating information in the most energy efficient way. Cetintemel et al. uses a dissemination tree and a dissemination schedule to control when and where messages are sent [7]. Shih et al. uses physical layer aware algorithms and protocol to save energy [8]. Akan and Akyildiz worked on effective reliable transport in sensor networks [9].

Our work focuses on creating an energy efficient addressing scheme. There has been several addressing schemes proposed in the literature. Schurgers et al., [10] reuses MAC addresses based on the connectivity of the sensors. Nodes are only known locally however, there is no way to refer to a node in an absolute way. Our method uses cluster similar to that proposed by Su and Zhang [11] who focused on optimal transmission range a clustered multi-hop network. We also group sensor nodes into cluster, but focus our work on finding an addressing scheme that saves as much bit rate as possible.

We also took ideas from other networks, namely the internet protocols and cellular networks in creating our addressing and routing schemes. Internet addressing uses the Classless Inter-Domain Routing addressing scheme [12, 13] which separates address into network and host addresses. Based on this idea, we separate an address into cluster and node addresses.

Our work also focuses on using mobile equipment. It is important that messages are routed to mobile equipment, no matter where it is located. We use a similar solution to that of mobile IP [14, 15]. A mobile system has an address at the base system, and has a mobile address at their current position. All messages sent to the base system are forwarded to the current position.

3 PROBLEM SPECIFICATION

An addressing scheme that can be used for a wireless sensor network which is directly accessible by various mobile users is described. The addressing scheme shown here must be very power-efficient. In this section we describe the basic characteristic of the network as well as the various assumptions we make about the network.

3.1 Network Assumptions

The two main entities in this network are the wireless sensor nodes (sometimes simply called node(s)) and mobile equipments (ME).

The sensor nodes are small; battery powered, and can measure an environment characteristic in a small area (such as temperature, or humidity). Batteries in a sensor node are not usually changed; instead the node is discarded when the batteries expire. Sensor nodes are usually very simple, and should not be used to handle extremely complex/extremely memory intensive protocols.

Sensor nodes communicate with one another and with other objects using electromagnetic waves. Sensor nodes have transmission range ranging anywhere from a few meters to 100 meters [16].

We also assume that the topology of the sensors may change or be moved by outside forces. The sensor network that we are working with is a dense network having the radius of a sensor signal to be at least twice the average distance between 2 sensors.

In our scheme, we use the notion of super nodes. Supernodes do not generally measure the environment. The supernode takes care of addressing and networking issues for nodes as well as mobile equipment. Supernodes will have the same transmission range as normal sensor nodes.

To reduce the address bits, we divide the nodes into clusters. Each supernode is the head or center of the cluster. The supernodes are fixed in place and generally understand more complex protocols than nodes for arranging its cluster. Supernodes may merge responses from the various sensors in its cluster to create a single message when the multiple sensors are expected to respond to the same request, thus reducing overhead bits required for its transmission.

Mobile equipments are used by users and communicate with the sensor network through the supernodes. In the type of application we are looking at, mobile equipment would query for information in a particular location. Unfortunately, there are drawbacks to storing the relation between sensor and location. First of all there would be too many to store. Secondly, even though there have been efforts to find the sensor's location [17, 18, 19], these techniques are still approximate. Finally, mobile equipment may change position over time due to external forces. Because of this mobile equipments do not communicate directly to the sensors, instead it communicates with a supernode in the general area of the location of the query.

A mobile equipment moves anywhere in the network range and gets data from any location in the network. It is the job of the networking scheme to route messages from and to the supernode that the mobile equipment is communicating with.

All sensors, super sensors and mobile equipment have equal signal range, a unique MAC address ad evenly distributed over the area. A picture of an example network is shown in figure 1

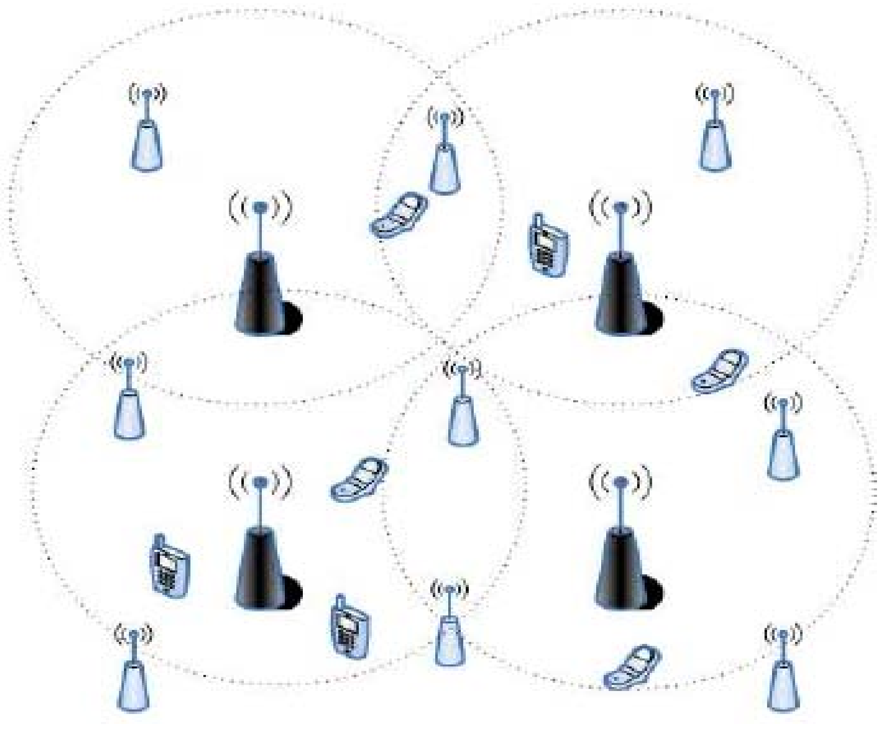


Figure 1: An example of the wireless sensor network for our schemes. The black transmitters are the supernodes and cluster centers, while the white transmitters are the wireless sensors. The mobile equipment is the other icons strewn about the area. Circles represent the cluster/grouping around the cluster centers.

3.2 Message Types

In order to apply the scheme to the widest possible set of application, we attempt to categorize the various messages in a system. In the comparison section (Section 5), we will show the efficiency of our addressing scheme by comparing the number of address bits for the various messages with other methods.

1. Setup Messages. These messages are used to setup the network. One element of setup is assigning addresses to nodes. Another use for setup messages are for calculating the route from one point to another.

2. Node Unicast. Messages of this type are sent from a node to a specific node within its transmission range. Messages of this type must be differentiable from non-unicast messages so that a node can ignore messages that are not designated to it. These messages must have two addresses, the sender's address and the receiver's address. Both addresses must be unambiguous in the nodes' transmission ranges. Unicast message include messages between cluster centers and nodes.

3. Broadcast. Messages of this type are sent from a node to all nodes within its transmission range. Messages of this type must be differentiable from unicast messages. All nodes hearing the messages must process the messages. Broadcast messages must have the sender's address.

4. Multi Cluster Messages. Multi cluster messages are used when a node needs to send data to another node outside its range and in a different cluster. This is done by moving the messages through the various clusters controlled by the supernodes. Multi cluster messages are mostly used to send messages to and from mobile equipment and sensors that is not in the same cluster area.

4 CLUSTER-9 ADDRESSING SCHEME

Given a set of n nodes in an area, we divide the n nodes into c cluster. Each cluster has a single supernode that can send and receive messages directly (without using intermediary nodes) to all nodes in its cluster.

The supernodes are arranged manually, with each supernode having a cluster number. In each cluster, each node is given an address A_n from 1 to n', where $n' = n/c$ or the number of nodes in each cluster. The address 0 is given to the supernode.

The number of mobile equipment expected at any given time in the whole system is given as W. A mobile equipment must be registered at all cluster that they communicate with. A soft state model is used where the mobile equipment must periodically register with all clusters they wish to communicate with. The maximum number of wireless equipment that a cluster can be communicating with in a given time is w, where $w < W$.

Because the cluster must also store the address of all mobile equipment that it is in communication with, w must be added to the total address needed for each cluster. Therefore each cluster must allocate $n_c = n' + I + w$ addresses, consisting of the n' nodes, the address for the node center, and finally addresses for wireless networks.

One of the main tenets of an addressing scheme, especially a reusable one, is that there may not be any ambiguous addresses. In order to do this, each node address is a combination of the cluster address and the node address (A_cA_n). We use a reusable cluster address instead of an absolute cluster address, that instead of using an address range of i.e., we use 1..9(4 bits) as cluster addresses (See figure 2 for cluster placement).

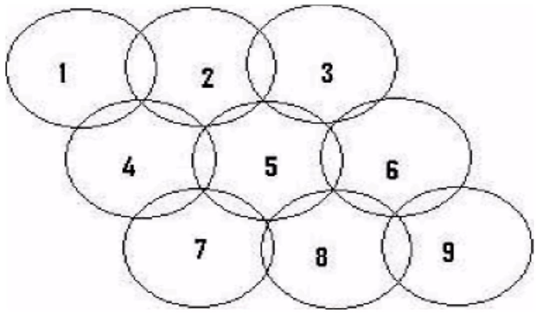


Figure 2: Location of the 9 clusters

The reason that nine cluster numbers are used, is that with 9 clusters, any messages sent will be unambiguous. Two clusters next to each other may not have the same cluster number. Any node may not have two or more nodes having the same address in its transmission range. An example of this is shown in figure 3, the node 3-15 has 2 nodes addressed 4-20 in its transmission range.

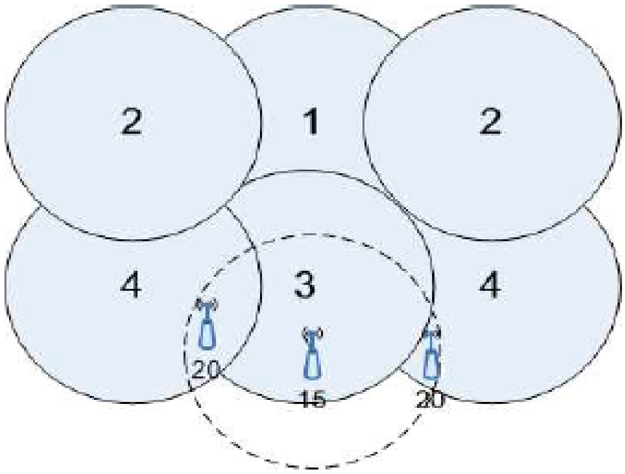


Figure 3: Ambiguous Addresses Example

4.1 Addressing Bits

4 bits is used for the cluster address. The first 9 address (0..8) is for the cluster number. This leaves 7 more addresses for other things. The other 7 address will be used to denote special message types. The number of bit for the node address depends on the number of nodes in each cluster n_c.

Each supernode has an absolute address that is based on the number of clusters in the whole system. A_s is the absolute supernode address, which is in the range of of l..c.

It should be noted that the bit length of all addresses are a constant that is known to all nodes (initially, it is known only to the supernodes). There is no need to send the length of address information as part of the message.

4.2 Address Setup

There are two types of address setup, the supernode address and cluster setup and the node address setup. The supernode address and cluster setup is only performed when initially setting up the sensor network. The node address setup is performed at the initial network setup as well as at regular intervals due to the possibility of nodes moving.

The supernode address is assigned manually according to the location of the supernode. The supernodes are placed and organized into a grid. The supernode address is simply the count of each supernode, from the top-left corner of the grid, going row-wise, from top to bottom. The most efficient utilization of addressing, would require the number of cluster per row (n_{cr}) and column(n_{cc}) to both be a power or 2 as this would utilize all the bits for identifying Supernodes without any waste. This would mean that the first *Log* (n_{cr}) bits are used to identify the row and the remaining bits to identify the column of the super sensor in the grid.

The cluster number of the supernodes are also manually assigned. For each 9 supernodes in an area, the supernodes are numbered 1 to 9 in an identical format. The simplest would be the first 3 across the top, followed by 4th to the 6th cluster at the second row, and the 7th to the 9th cluster at the bottom. The area next to this area will repeat the cluster address.

This cluster address is used in the identification of the address of the next hop and is an integral part of the routing algorithm. Since the numbering convention is fixed, if a cluster is assigned a cluster Address of 5, then it know that clusters 4 and 6 are to its left and right respectively and 2 and 8 are to its top and bottom respectively and 1,3,7,9 are to its top left, top right, bottom left and bottom right respectively. Similarly, for all other Cluster addresses the next hops are fixed with respect to position.

To set the node address, all supernodes broadcasts a message (Message 1) with the setup address (we use 9 or 10012) to all sensors. The message contains the cluster number of that supernode. As well as a message type of 0, which designates that this message comes from a supernode.

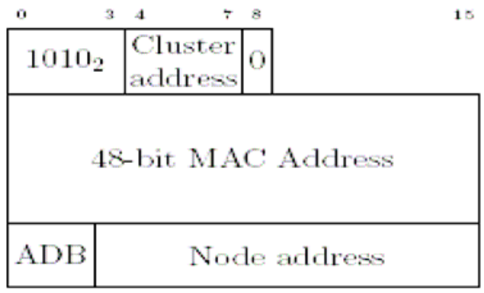
0 3	4 7	8
1001_2	Cluster address	0

Message 1: Setup messages sent by supernode

0 3	4 7	8 15
1001_2	Cluster address	1
48-bit MAC Address		

Message 2: Setup messages answers by a node

Each sensor that receives the broadcasted message, replies by sending a setup message back to the supernode. The message starts with the setup address 9, followed by the 4 bit cluster number, the message type 1, and finally the node's absolute MAC address (Message 2). The supernode replies with another message offering an address. The format of the message is that it starts with the setup address 10 (1010_2), followed by the cluster number, the message type (0), the node's MAC address, the bit length of the address (ADB), and the node address that it offers (Message 3). If the node accepts the offer then it will reply with the exact message, only with a message type of 1.



Message 3: Address offer from supernode

A node may be in an area where it can hear and receive messages from more than one cluster, in this case, the node chooses the cluster offering the lower-numbered node address

4.3 Sending Messages

In this scheme, unicast messages include node unicast messages from a node to any other node in its transmission range, as well as messages to and from a supernode. All unicast messages are single hop messages. Every unicast message simply uses the sender's and the receiver's address which consists of cluster address and node address (Message 4). Nodes can send messages to nodes in different clusters, as long as the other node is in its transmission range.

0	3 4	7 8		
Cluster address	Node Address	Cluster address	Node Address	Message

Message 4: Unicast Messages

Broadcast messages uses a special address. Broadcast messages is sent using address number 15 (11112). Broadcast messages include the sender's node address so that any receiver knows how to reply (Message 5).

0	3 4	7 8	
1111_2	Cluster address	Node Address	Message

Message 5: Broadcast Messages

It may be necessary for nodes to send data accross the network area to a distant cluster. When data is sent accross networks, the message sends it to the a special address 12-14. The supernode is responsible for routing messages to and from one another. Each supernode knows the route to any other supernode via the next cluster. No special routing discovery algorithm is needed, since supernodes are arranged in a grid.

For example, when the number of clusters per row and column are both multiples of the power of 2, the first log((n_{cr})) bits of the destination are used to identify whether the next hop should be above, below on on the same row depending on whether its greater, lesser than or equal to the nodes own address respectively and the remaining bits (the last log((n_{cr}))) when compared with the supersensors own address, identify whether the next hop should also move to the right, left or continue straight if greater, lesser or equal respectively.

A multihop message will be forwarded from cluster to cluster (via the supernodes). Using both this information the next hop can take 8 distinct positions which are represented by the 8 number from 1 to 9 barring the number assigned to the cluster itself. The message specification for multihop message are given in section 4.4.

However our scheme does not allow supernodes to talk directly to each other. This is to reduce the number of supernodes required in the setup of the network. Messages are forwarded (repeated) by nodes that are in the transmission range of both supernodes (figure 4). There may be more than one node that is in the cluster intersection area. If so, only one node may repeat the message. This is achieved by having the sensor transmit the message after a short random amount of time. If during this short random time, the node sense that the message has been repeated, it does not forward the message.

4.4 Mobile Equipments

The mobile equipment must setup a home address in a cluster area that it is in, similar to the home address concept with mobile IP. The mobile equipment may have more than one home address in more than one clusters. It is recommended that the mobile equipment changes home address every time the mobile equipment moves.

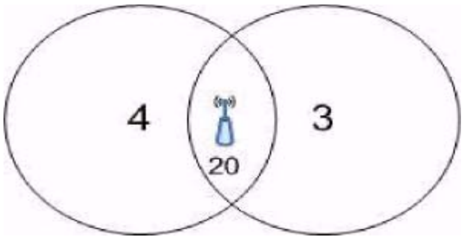


Figure 4: In this node, multihop messages that are sent to cluster 3 from cluster 4 (and vice versa) may be repeated by node 4-20

To setup a home address, the mobile equipment sends a mobile request address message. This message starts with the address 11 (1011_2), followed by the MAC address of the mobile equipment 6. Any supernode listening to the mobile equipment sends out a address offer, similar to the address offer to a node by using the setup address 10 with an additional field of the supernode address (see Message 3). The supernode address is stored by the mobile equipment for updating its location in the future. The mobile equipment confirms the offer by sending an accept address offer message (message is similar to a node's accept address offer message).

0 3 15

1011_2
48-bit MAC Address

Message 6: Address request from a mobile equipment

In a GSM system, an ME regularly communicates with the base station it is associated with to keep track of which cell it belong to. The ME here too will regularly communicate with its supersensor to confirm that it is still within the same cluster. When an ME moves to a new cluster area. It must acquire an address for itself in that cluster. If the mobile was already assigned an address when it belonged to another cluster, the mobile appends the old address (supernode address, and the node identifier in the home cluster) to its setup address (packet starting with address 11) that it send to the supersensor.

The supersensor then sends a message to its home addresses to forward messages to its current location. The supernode cluster sends a message starting with an address of 12 (1100_2). The message consists of the current supernode address, and the node identifier of this mobile in this cluster, followed by the home supernode address, and the node identifier in the home cluster, and finally the next cluster hop. This gets forwarded by the network to the old home location (Message 7). The home address supernode will then update its database to forward all messages to the new address.

1100_2		
Supernode Address	Node Address	} sender
upernode Address	Node Address	} receiver
Next Cluster		

Message 7: New address information message

We use a soft state model. The mobile equipment must at interval send an address 12 message to its home base. If after a certain time, no messages are received, the home supernode may delete the address from its database. The mobile equipment should stop sending messages to one of its home base once it expects no message from that base.

Messages number 13 and 14 are used to send messages from mobile equipment to and from another cluster. Message 13 (1101_2) is used when sending a message to a supernode, and consists of the home supernode address and the node identifier, followed by the target supernode address, and finally the message (Message 8). The receiver supernode address may either directly answer the message or forward the message to one of its sensor nodes. If it does the latter, it first allocates a local wireless address for this message. It then sends a message (either a unicast or a broadcast) to the node(s), with the newly allocated wireless address as the source address.

0 3 15

1101_2		
Supernode Address	Node Address	} sender
Supernode Address		} receiver
Next Cluster	Message	

Message 8: A message from a mobile equipment to a supernode

Once an answer is obtained. The target supernode sends a message back to the mobile equipment using message 14 (1110_2) (Message 9). This message consists of the sender supernode address, the mobile equipment's home address as well as the node address. This message is forwarded to the home address. If the sender allocates a wireless address in the cluster, it should delete that newly allocated address from the database, since there is no longer need for it.

0 3 15

1110_2		
Supernode Address		} sender
Supernode Address	Node Address	} receiver
Next Cluster	Message	

Message 9: A message from a supernode to a mobile equipment

Once the message arrives at the home address, the home address may either send it via unicast to the mobile equipment (if the mobile equipment is still located in the cluster), or forward it to its current address. To forward the message, it changes the target address of the message to the mobile equipment's current address.

5 EVALUATION

We compare our method with a numbered scheme. In the numbered scheme each node and mobile equipment is given an address of $1...n + w$. We assume that any node knows where all other nodes are, and all nodes know how to route to another node.

5.1 Without Mobile Equipment

We first compare the addressing scheme without the use of mobile equipment $(W = 0)$. This simplifies the problem somewhat by making it easier to analyze. Furthermore current wireless sensors infrastructure does not utilize mobile equipment, therefore this section will show how this addressing scheme can be used to increase efficiency.

For the numbered scheme, the number of bits needed to uniquely identify each node is given in equation 1. Which is simply the number of bits needed to represent n (the number of nodes in the system).

$$Bn=[(\log_2 n)] \quad (1)$$

One reason a fixed address scheme was not used in comparison with our scheme is that the fixed address scheme using IP or MAC address is similar to the numbered scheme with $B_n = 32$ for IPv4 or $B_n = 48$ for MAC. This is a constant that is worse than using numbered addressing scheme.

For our clustered methodology, each address is given a 4 bit cluster address. However node addresses are reused, so a total of $n' + 1$ address per cluster is used, where c is the number of clusters and n' is the number of nodes per cluster. The 1 in that equation is the address for the supernode. The number of bits used is given in equation 2

$$Bn=[(\log_2 n'+1)]+4 \quad (2)$$

The next question is how many bits is actually saved for a particular system. This is calculating given the same number of nodes, how many bits are needed for the numbered scheme, and how many for the clustering scheme. This is simply $B_n — B_c$. A negative value simply means that the clustered addressing scheme actually returns a higher address bit count than that of the numbered scheme. The following equation shows how to calculate the bit savings

$$\begin{aligned}
&Bn - Bc \\
&= [(\log_2 n' * C)] - ([(\log_2 n'+1)]+4) \\
&= [(\log_2 (n') + \log_2(c)] - [\log_2(n'+1)] - 4 \\
&=[(\log_2 (n')] - [\log_2(n'+1)]+[\log_2(c)] - 4
\end{aligned}$$

Based on the equation above $[(\log_2 (n')] - [\log_2(n'+1)]$ 1 is always going to result in a negative number. Therefore, the main factor in this equation is the number of clusters. If $c < 16$, then it is impossible to have any savings.

However, it must be noted that depending on n', a large c may still not create any address bit savings. Table 1 shows the number of bits needed for the numbered scheme and our clustered scheme for various c and n'.

Figure 5 shows the number of savings for a cluster for various values of n'. Looking at the average savings over the various values of n' it is easy to see that the bigger the number of cluster, the higher the savings.

5.2 With Mobile

If MEs are factored in the equation, then the address space for each cluster must also expand depending on the number of equation. Specifically, the equation for the number of bits needed for addressing in each cluster ***(B_c)*** is shown in Equation 3

$$Bc = [\log_2 (n'+W+1)]+4 \quad (3)$$

It is difficult to find a simple formula that generalizes bit savings for this concept. Each condition must be examined individually to see whether there are any address bit savings. Table 1 shows the bit savings when wireless is used for some cluster number and number of nodes in a cluster. Figure 6 shows the effect of adding mobile equipments (w) in bit savings. The more mobile equipments added, the lesser the bit saving, the exact value dependant on the number of clusters and the number of nodes in each cluster.

5.3 Address In Message Transmission

The efficiency of a scheme cannot just be measured by the savings in bit length of individual addresses. Another aspect of efficiency is how this addressing scheme translates in message transmission between nodes. In this paper, we compare the different schemes based on three different types of messages, unicast messages, broadcast messages, and multi-cluster routable messages. Setup messages are considered to be overhead, and will be dealt in section 5.5. Messages to and from center cluster and to nodes is basically unicast in our scheme, as clusters are one hop away from any of its nodes.

Table 1: Bit savings for various configurations of cluster numbers and node clusters

Cluster Size	Nodes Per Cluster	Mobile Equipment	Total Sensors	Bitlength (Numbered)	Bitlength (Cluster-9)	Savings
5	20	0	100	7	9	-2
5	100	0	500	9	11	-2
20	20	0	400	9	9	0
20	30	0	600	10	9	1
20	30	40	640	10	11	-1
20	90	20	1820	11	11	0
20	100	0	2000	11	11	0
40	15	0	600	10	8	2
40	15	10	610	10	9	1
40	40	0	1600	11	10	1
40	40	15	1615	11	10	1
40	40	30	1630	11	11	0
100	5	0	500	9	7	2
100	100	20	10020	14	11	3
3600	70	40	252040	18	11	7

5.3.1 Numbered Scheme

For unicast messages two addresses (sender's and receiver's) are needed. Therefore the number of address bits needed is

$$B^n_{unicat=} \; 2 \;\; X \;\; Bn \quad (4)$$

Similarly, for broadcast message, two addresses are needed, the sender's address and the broadcast address. The broadcast address must be the same bit size as any other addresses.

$$B^{n}_{broadcast} = 2 \times Bn \quad (5)$$

Finally for multi-cluster routable messages, four addresses are needed, the routing address to differentiate this message from all the rest, the sender's address, the receiver's address, and the next hop address.

$$B^{n}_{routable} = 4 \times Bn \quad (6)$$

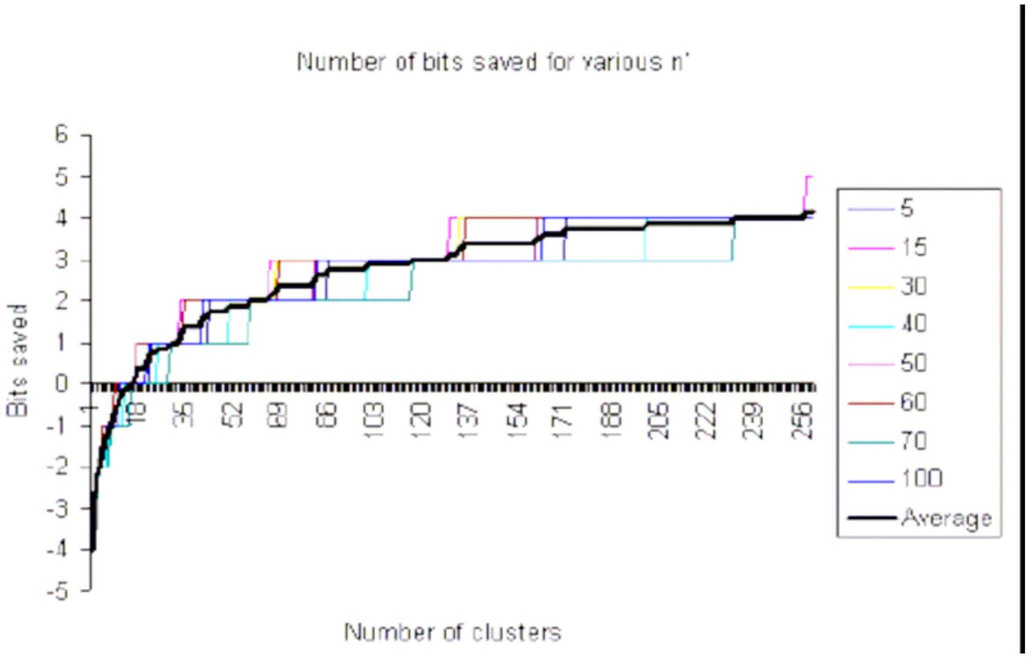


Figure 5: The number of bits saved for different cluster numbers (1..255)

5.3.2 Cluster-9 Scheme

In the clustered scheme, the unicast message will also have two addresses (sender's and receiver's). The number of address bits needed is

$$B^{c}_{unicat} = 2 \times Bc \quad (7)$$

The broadcast address is a special 4 bit address instead of a cluster address, thus the number of address bits needed with this scheme is

$$B^{c}_{broadcast} = 4 + Bc \quad (8)$$

The multi-cluster message needs a routing address, which is 4 bits, the address of the sender and the receiver, as well as the next hop to get to the supernode. We do not need an absolute node address to get to the receiver; we only need the absolute supernode address. The absolute supernode address of the sender and the receiver is simply the supernode number which can be represented in $|\log_2(c)]$ bits. The mobile node address is just the node address in the cluster headed by the supernode *(B_c* — 4). The next hop is simply the cluster number (0..8) (4 bits). The number of address bits needed is:

$$B^{n}_{routable} = 4+2(\log_2(c))+(Bc-4)+4 \quad (9)$$

5.3.3 Total Savings

The total savings for the three type of messages are:

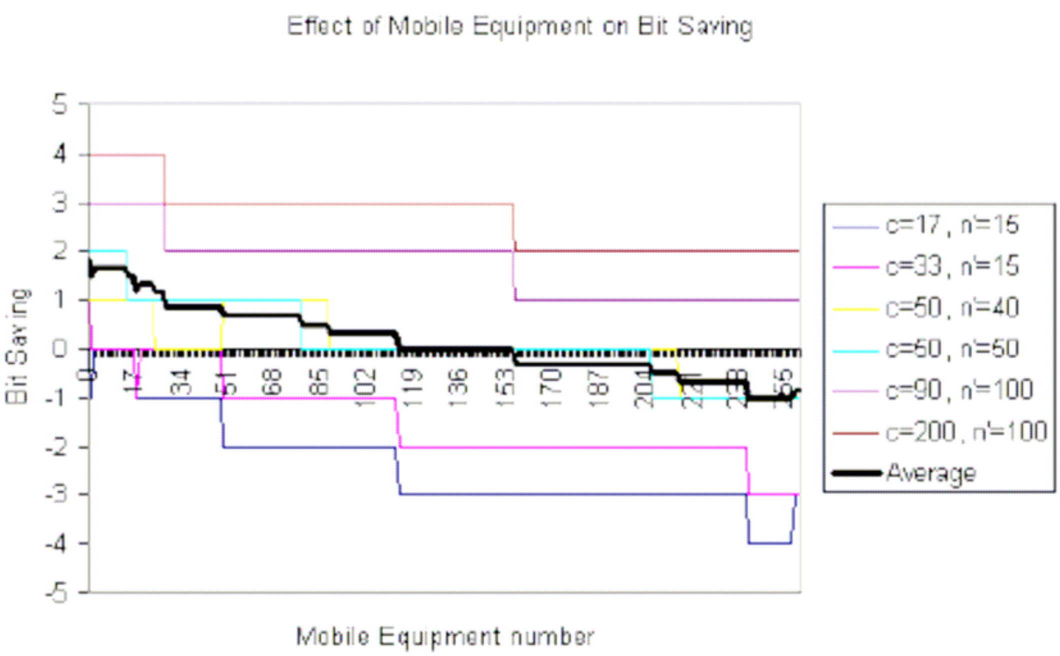


Figure 6: The number of bits saved for different mobile equipment numbers (1..255)

$$\Delta B_{unicast} = 2X(B_n - B_c) \quad (10)$$

$$\Delta B_{broadcast} = 2 \text{ X } B_n - 4 - B \quad (11)$$

$$\Delta B_{routing} = 4 \text{ x } S_n - 4 - (2 \text{ x } \log_2(c)) - B_c \quad (12)$$

Even when there is no savings in the number of bits for addresses $(B_n \leq B_c)$, our addressing scheme may still have some savings when doing broadcast and routing messages to messsages in different clusters.

Table 2 shows the total savings for various values of n', w, and c. The bits saved for a single message is modest. However, nodes will be sending multiple messages, and that adds up the saving. Furthermore in a system, there will be more than one node, so the saving in bits over the system is quite significant. The total header bits sent out for a node is the number of bit headers multiplied by the number of unicast messages (M_u), broadcast messages (M_b,), and routing messages (M_r).

$$B(Ni) = M_u \text{ X } B_{unicast} + M_b \text{ X } B_{broadcast} + M_r X B_{routing} \quad (13)$$

$$\Delta B(Ni) = B(Ni)^n - B(Ni)^c \quad (14)$$

5.4 Memory Overhead

The scheme described in this paper does not force the sensor nodes to have significant memory requirement. There is no memory requirement sacrifice in order to achieve the bit savings shown. For a sensor node, memory space is needed to remember the clusters that it can communicate with (a total of 8 bits) and its current address. Super nodes use more memory for addressing purposes, storing information about the various mobile equipment addresses, as well as routing information

Table 2: Total system savings for various configurations of cluster numbers and node per clusters. System savings is for 50 unicast messages, 50 broadcast messages and 50 multi-cluster

Cluster Size	Nodes/ Cluster	Wireless Nodes	Sensor Nodes	Unicast Savings	Broadcast Savings	Routable Savings	System Savings
5	20	0	100	-4	1	9	30,000
5	100	0	500	-4	3	15	350,000
20	20	0	400	0	5	13	360,000
20	30	0	600	2	7	17	780,000
20	30	40	640	-2	5	15	576,000
20	90	20	1820	0	7	19	2,366,000
20	100	0	2000	0	7	19	2,600,000
40	15	0	600	4	8	16	840,000
40	15	10	610	2	7	15	732,000
40	40	0	1600	2	8	18	2,240,000
40	40	15	1615	2	8	18	2,261,000
40	40	30	1630	0	7	17	1,956,000
100	5	0	500	4	7	11	550,000
100	100	20	10020	6	13	27	23,046,000
3600	70	40	252040	14	21	33	856,936,000

5.4 Setup Overhead

The scheme proposed in this paper involves the physical setup of the nodes in the network, which is only done once during the installation phase, and the setup of the individual nodes, which is done both during the installation phase and at a regular interval of time.

Once the super sensors are setup in the network, the sensors may be scattered over the area covered by the grid such that the average distance between two sensors is less than half the transmission range of the sensor. This ensures that there is sufficient redundancy for transmission.

Once the sensors are physically setup, the address setup will have to be performed as described in Section 4.2. During the setup phase, a number of bits will be sent from the super nodes to the mobile sensors. The nodes must reply according to the protocol described above. The total number of node overhead bits is shown in equation 15. The total number of bits consists of the original broadcast message by super node, the answers from each of the nodes, and the address offer for each node.

$$\begin{aligned} Onode &= c(4 + \log2(c) + 1) \\ &+ n(4 + \log2(c) + l + 48) \\ &+ 2n(4 + \log_2(c) + 1 + 48 + \log_2(\log_2(n' + w)) + \log_2(n'+w)) \end{aligned} \quad (15)$$

Another overhead concurred with this scheme is mobile node setup. The total number of overhead bits for mobile setup is shown in equation 16. The mobile setup messages consists of the request by the mobile equipment, followed by the address offer and acceptance for each mobile equipment, and also includes the number of times that a mobile equipment changes cluster (which is signified with m in the formula).

$$Omobile = W(4 + 48)$$

$$+ 2w(4 + \log_2(c) + 1 + 48 + \log_2(\log_2(n' + w)) + \log_2(n' + w)) + 2 \times w \times m(4 + \log_2(c) + \log_2(n' + w) + \log_2(c) + \log_2(n' + w) + 4) \quad (16)$$

6 CONCLUSION AND FUTURE WORK

We describe an addressing scheme that saves energy in a wireless sensor network where sensors must communicate with mobile equipments. Our scheme divides the network into clusters. A super node is put in charge of each cluster. The super node is in charge of assigning address to every node in the cluster as well as routing messages between clusters.

Users with mobile equipments are able to obtain information from the network. Mobile equipments are also assigned addresses at each cluster. The mobile equipment communicates mainly with super nodes in distant clusters.

We show that savings differ greatly depending on the number of clusters used as well as the number of sensor nodes placed in each cluster. A method to do quantitive analysis of the number of bits saved is also given in the text.

Our method does not significantly increase the memory requirement for every node. However we show that our method significantly reduces the number of bits transmitted during the course of sending messages. The number of bits saved depends on the number of clusters. Our method saves only when the sensor network is quite large and has a large number of clusters.

The scheme proposed here can be improved using various ways. Currently, super node addresses are assigned manually. These addresses should be automatically generated based on the location of the super nodes relative to other super nodes. Likewise, cluster addresses should also be automatically generated.

Currently, super nodes are placed in a grid. A method to use this algorithm when super nodes are randomly placed should be investigated. This will allow super nodes and nodes to be placed the same way, for example simply by throwing them around. Other power saving methods that have been proposed earlier, such as those that work by turning off the receiver at scheduled times or for calculated intervals when a sensor isn't expecting a message, can be coupled with the model proposed to further reduce power consumption by the sensor.

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