Wireless Sensor Network Cluster Formation at the Presence of a Wireless Mesh Network

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***Abstract*— Countries under development have recently benefited from the emergence of networked communities operating in an infrastructure poor environment. We describe a WSN protocol for monitoring quality of life in such networked communities. The protocol bridges a IEEE 802.15.4 to a IEEE 802.11 network using a presence advertising algorithm.**

I. Introduction

Health status (together with education) represent the two major challenges for those parts of the developing world that have found solutions on drinkable water and nutrition. An interconnected community (even with limited or low-quality access to a backbone network) has the means to support activities aiming at facilitating disease management and health status control within a larger (to the community) population. Such activities may include the implementation of scenarios in which a Wireless Sensor Network (WSN) coupled with an electronic community infrastructure supports monitoring, processing and transmitting of personal, ambient and environmental parameters.

Our main contribution is the proposed novel simple and energy-efficient cluster tree reorganisation algorithm of the WSN as a result of topology changes caused by mobility of the Wireless Mesh Network (WMN) nodes. Our aim is the performance analysis of the protocol in terms of connection time, traffic and power management..

II. Network Formation

In our problem definition we identify two networks. A WSN that collects QoL parameters, like the environment (water, soil, air, volcano), vital signs, health related human receptors, behavioral patterns. This is referred as cloud A. Usually in the literature the sinks are considered part of the WSN. Our case scenario examines a different setting in which the sinks form a different network, Cloud B, which acts as a store & forward facility for the acquired data. In our framework Cloud B is implemented by networked communities that pre-exist for some other reason or are formed for this particular case. Examples of such network communities may be found in a OLPC equipped village [1], a mobile phones sharing cooperation [2] or a hospital on wheels [3].

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For the purposes of our work here we assume that Cloud B is an ad-hoc WMN IEEE 802.11s network and Cloud A an IEEE 802.15.4 WSN. The generality of these assumptions is enough to ensure wide applicability of the proposed solution.

The problem of bridging IEEE 802.15.4 and 802.11b networks has recently been studied for healthcare applications [5]. However, in that case the two networks are assumed static unrelated networks. In our case, however, the 802.11s network nodes move arbitrarily and when arriving in the WSN proximity they act as 802.15.4 sinks. This formation represents the realistic scenario of building a monitoring sensor network in the vicinity of a networked electronic community. Cluster heads and network coordination is assumed by Cloud B nodes. This results in higher energy efficiency and longer lifetime for Cloud A. A beacon mode with a superframe is used.

Each node advertises itself as a sink to Cloud A. This is achieved by having each node broadcast a Presence Entry. All motes that receive the Entry and do not have a one-hop relation to another node set the advertising node as their sink. Motes that already have a one-hop relation with a node ignore the invitation In this case the network topology does not change in the child tree branches of these motes.

The motes that decide to accept the node as a cluster head, become hop 0 motes for this cluster. The first node that arrives in the proximity of Cloud A assumes the role of the coordinator of Cloud A (Fig. 1-top). All subsequent nodes will form independent clusters. The coordinator could act as a gateway to the outer world as well; other nodes may also act as gateways. The coordinator role may be transferred between nodes.

Nodes broadcast Presence Entries as they move. When a mote establishes a direct connection with a node, it informs its neighbors; for this purpose it transmits a Presence Entry itself. Motes with a 2 or higher hop distance transverse their traffic to the mote in question. It may be that the parent of this mote will now become its child (Fig. 1-bottom). In general, whenever a node sends a Presence Entry the following changes in the routing path may occur (in all cases motes disassociate from their past parent node and associate with the new one):

a. Cloud A links break for the motes that connect directly to the node.
b. Cloud A links reverse for the parent motes that decide to use a (new) route to case a. motes.
c. New cloud A links are formed; for each link formed one link disappears.

Motes propagate backwards the new routing status. When any of the above changes occur a new clustered tree network topology is formed.

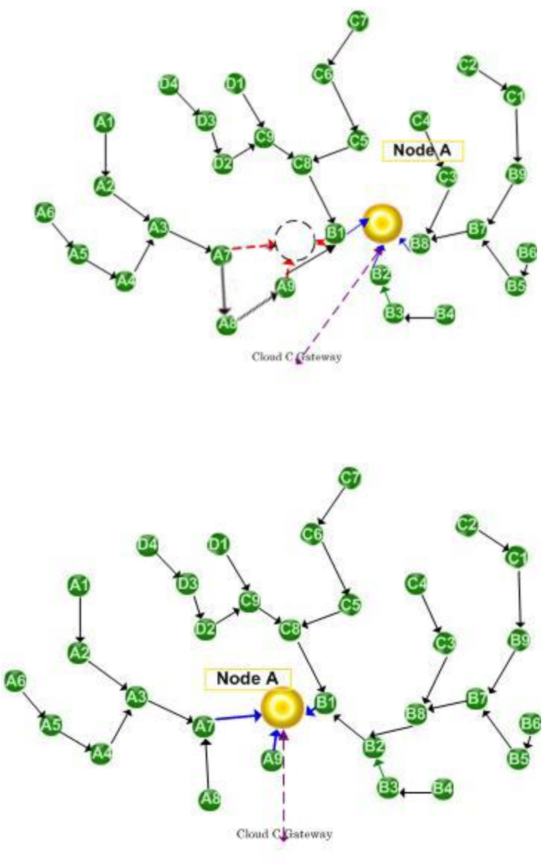

Fig. 1 Network Formation as a result of (Cloud B) Node A mobility

A node before advertising its presence must consult the already participating nodes. For this reason it broadcasts over the WMN (Cloud B) a cluster availability request. All nodes will propagate the request to the whole network. When this request reaches the coordinator node it will reply by denoting the PHY channels that are used by the participating nodes and their IDs. The coordination node will additionally denote its role. When this information is available the node will choose one of the remaining channels and will send its Presence Entry. If it does not receive an association request from at least one mote within the interval set by the coordinator, then either there are no (interested) motes in its range or it is using an occupied channel. The node will try again broadcasting in the WMN at random intervals. Once it receives an Association Request, it will acknowledge it and broadcast the new cluster information to the WMN. This will also support locking the channel for other interested nodes. The cluster information is maintained by the Cloud A coordinator. All cluster internetworking, including formation and release of clusters is performed in Cloud B.

Although the IEEE 802.15.4 MAC Disassociation Command may be used for nodes leaving, the most usual reason for disassociation of Cloud B nodes is mobility. Therefore, such a command is not very useful (power shut down could be one case where this Command could be useful; exploitation of an accelerometer functionality is another one). Our CL protocol uses the following mechanism for cases where the Disassociation Command can't be issued.

A node must inform all connected motes every τ seconds on its status. If a child hop 0 mote does not receive a Presence Entry from the node at which it is connected for t>2τ then it transmits a Query Beacon to that node. If after 2τ the mote still has not received a Presence Entry it concludes that the node is no longer available and tries to connect to other available nodes stored in the look up table it maintains. If such nodes are not available or if the look up table is empty the mote establishes its default Cloud A link and informs its default parent mote. Then it also informs all its neighbor motes (at child status by definition of the protocol) that had previously assigned themselves to its cluster so that they link to another node or return to their default status following a similar procedure to the one described above for hop 0 motes. Cloud A broken links (due to e.g. power exhaustion, hardware failure or mote movement) are treated as in IEEE 802.15.4 cluster-tree topologies [4]

III. Analytical Model

We assume our WSN has a sleeping policy for each mote and aim to calculate the event detection reliability R (minimal prescribed packet rate) as in [7]. Solving the Markov model for one Cloud B node we have

$$R = n\lambda\left(1 - P_b\right) \quad (1)$$

where 1/λ is the packet interarrival time, n the number of motes and

$$P_b = 1 - \frac{1-v}{\lambda n_A} \quad (2)$$

with v the probability for vacation period after Markov point (return from sleep and end of transmission) and n_A is the average distance between two consecutive Markov points in sec of Cloud A motes, which depends on the random sleep period that determines the power consumption per mote. Thus, the cluster lifetime depends on the required event reliability and the number of motes.

Eq. (1) and (2) is the result of the fact that the idle state of the Markov chain is reached when the buffer is empty after transmission. Since the packet arrival rate to the node in the source cluster is λ, then probability of zero Poisson arrivals during unit backoff period can be approximated with Taylor series.

When a second Cloud B node arrives, then

$$R=R_1+R_2 \quad (3)$$

R_1 and R_2 being the packet rates for the two clusters. One can derive from (1-3) that, because the number of motes of Cloud A remains constant, the arrival of additional nodes lowers the optimal packet rate increasing the mote lifetime.

We now change the Markov model so that we assume a multihop star topology. That would change eqs. (1) and (2). In this case v will lower as it is linearly dependent to the steady state probability that are k packets in each mote buffer immediately after packet service in the service period (active part of the superframe), as a result of serving other motes as intermediate hopes. Thus, as additional nodes enter power consumption drops because (a) the motes are assigned to different clusters and (b) the average number of hops decreases.

In fig. 2 we present the results of our analytical one-hop model (eqs. (1-3))for two and three nodes, assuming an equal number of motes assigned in each one of them, i.e. $n_1=n_2=n/2$, $n_1=n_2=n_3=n/3$ and a one level decrease of the average number of hops.

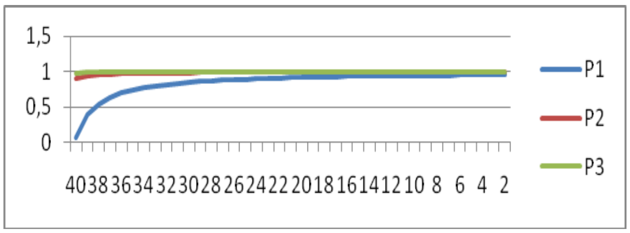

Fig.2 Average sleep probability for the case of one (P1), two (P2) and three (P3) Cloud B nodes as a function of Cloud A motes

IV. Model Validation and Discussion

We define presence as a new way of routing. Presence information identifies a mote in terms of its participation in a route (tree) in a sensor network. Our solution focuses on exploiting the collaboration of the two networks, achieving lower network formation traffic. The network formation protocol described here resembles design and performance issues of cluster interconnection for beacon-enabled 802.15.4 clusters. Our approach, in which the cluster coordinator is used to bridge clusters is known to be superior in terms of traffic. Note also, that in a simplified case, where enough nodes exist to cover the network area of Cloud A fully, i.e. so as all motes become hop 0 motes, then our protocol operates as a static LEACH network, which is known to have superior energy savings compared to other existing WSN MAC approaches [6].

Fig. 3 shows Opnet simulation results for a Cloud A of 50 sensors (Radio range of a sensor node 40 m, Packet length 30 bytes, IFQ length 65 packets, Transmit Power 0.660W, Receive Power 0.395W) randomly distributed in an area of 100mX20m and Cloud B nodes moving through at 2m/s on random paths. It is seen that on the average only three Cloud B nodes are enough to minimize required hops. Standard deviation shows not significant statistical error.

V. Conclusion

The main contribution of the work is the presence algorithm that defines a new way of routing. A realistic application scenario for use of this algorithm has been described. Implementation testing of the algorithm and verification of the simulation results are the next steps.

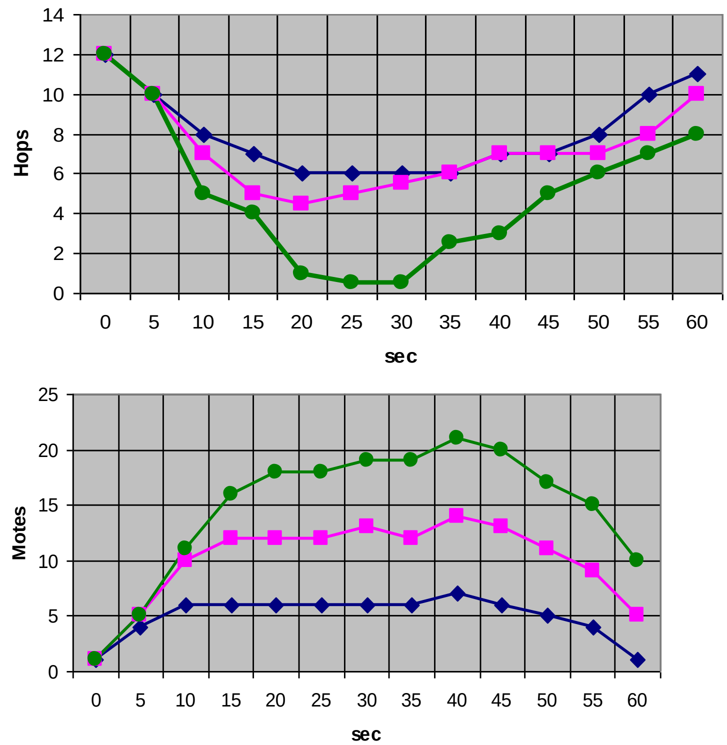

Fig. 3 Number of Hop 0 motes (lower) and maximum number of hops (upper) for nodes moving through the Cloud A area (averages of 250 repetitions). Cases of one (diamonds), two (squares) and three (dots) moving Cloud B nodes.

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