CLAP: Cross-Layer Protocols for Phealth

Pantelis Angelidis[1,2]

[1] MIT Media Lab
[2] University of W. Macedonia, Greece
pantelis@media.mit.edu

Abstract. We present a low cost, low power, backbone free quality of life monitoring solution, suitable for rural areas of countries under development. CLAP is an MIT/VIDAVO initiative that we envision as a turnaround approach on the way health and quality of life in these areas of the world are being addressed.

Keywords: Rural health, Wireless Sensor Networks (WSNs), Personalised Health (pHealth), ad-hoc networks, energy constrained networks.

1 Introduction

Wireless Sensor Networks (WSN) have emerged recently as a new networking environment that provides end users with intelligence and a better understanding and interaction with the environment. For instance, a WSN of wearable wireless vital sign sensors (including electrocardiogram, blood pressure, etc.) and mobile wireless display devices can be employed to monitor patient health in an outpatient environment (e.g. home or care center).This is one application of a research discipline is known as phealth.

Personalised Healthcare (phealth) is a collective term aiming to reflect all modes of patient-centric healthcare delivery via advanced technology means. Personalized health involves the utilization of micro and nanotechnology advances, molecular biology, implantable sensors, textile innovations and information & communication technology (ICT) to create individualized monitoring and treatment plans. pHealth proactively endorses the sense of "one-to-one" communication to elevate healthcare delivery, optimize patient services and ensure seamless from the patient point of view information exchange.

Recent developments in ICT technologies have enabled the creation of electronic communities of educated users in technologically poor or even virgin environments. Such examples may be found in initiatives like OLPC [1] or Moca [2]. Health status on the other hand, together with education, represent the two major challenges for those parts of the developing world that have found (even partial) 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 (e.g. a village or a number of adjacent ones). Such activities may include the implementation of pHealth scenarios in which a WSN-like infrastructure supports monitoring, processing and transmitting of personal, ambient and environmental parameters.

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Today's pHealth systems assume a technology advanced environment. Mitigating it to the developing world reality should take into account power consumption, network bandwidth and processing limitations. On top of that the community oriented health monitoring is a novel concept, that, to the best of our knowledge, we introduce it here for the first time.

2 Application Framework

Our conceptualized framework consists of four interacting clouds. Wireless sensor networks collect data monitoring QoL parameters, like the environment (water, soil, air, volcano), vital signs, health related human receptors, behavioral patterns. This is referred as cloud A. In this cloud, sensors are deployed in crucial parts of the rural areas, that could range from river banks, geographically challenging parts (for example; hilly areas), schools, gathering places, homes, down to individuals. The sensor networks could collect various critical data (e.g., level of water in the rivers which could help for flood warning, earthquakes etc.) and send them to gateways (sinks is a term widely found in WSN literature as well) referred as cloud B.

Usually each of the villages or rural areas has at least one cloud B installation. A cloud B acts as a store & forward facility for the acquired data. In addition to the data collected by the wireless sensor networks, a cloud B may support the collection of other useful data like demographic data, health care information (for example, swine flu reported cases in the rural areas of Mexico), agricultural information, etc. that could be manually or semi-automatically entered. Different solutions have been proposed in the literature to implement cloud B functionality, ranging from kiosk/truck [3], to satellite stations [1], to mobile phones [4]. **In our framework a 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, a mobile phones carrying community or a hospital on wheels, a vehicle mounted medical facility with wireless access functionality. A cloud B may move around the rural areas and serve many cloud A implementations or may be attached to only one and collect data only from them. As conceptualized here **cloud B is a distributed self-organised collect, store & forward facility.** One implementation approach to materialize a cloud B is to form wireless ad hoc networks based on PCs (or laptops as a matter of fact). Another approach is to form an NFC network based on mobile phones. A third one would be a tagging network based on RFID and spinners [5]. Independent of the implementation approach any cloud B is able to:

a) Collect data from cloud A installations
b) Store this data and (optionally) additional
c) (optionally) process all this data
d) Communicate data to the outer world

Data communication from a cloud B to the outer world is performed by facilities referred as cloud C. The major task of a cloud C implementation is to ensure reliable acquisition and delivery of data from the rural areas to a centrally located center referred as cloud D. A cloud C facility is capable of (wirelessly) communicating data acting as a repeater or router. It may additionally have capabilities for incoming data to be stored temporarily and/or processed. Examples of cloud C implementations may range from very simple solutions of one single PDA carried by a mailman or a drinking water distributor, to more complex facilities of satellite-linked equipment or vehicle mounted communication amenities.

A cloud D collects (processed or raw) data from cloud B installations communicated through the corresponding cloud C facilities. A cloud D would combine this data with data from other cloud A data and past records for a particular rural area or a number of selected areas and supply it to a referral center (which could also combine decision and action government powers). In this way, the government gets the timely and processed data from the rural areas and decides on the necessary actions accordingly. This data not only helps the government provide various services to rural areas and make educative strategic decisions and planning (as for example by monitoring behavioral patterns and socio-economic indicators), but could also help in emergency situations as well as for prevention (among the many examples one could think, virus spread, typhoon creation and floods give a sample that speaks for itself).

3 Network Formation Algorithm

We describe a sensor network formation algorithm to exploit the application environment in the framework presented previously. The sensing nodes (we will refer to them as motes in this paper) form Cloud A. The network is formed in four phases with the aid of an existing peer-to-peer WMN (Cloud B). The four phases are summarized in Table 1.

3.1 Phase 1: Assumptions and IEEE 802.15.4 Parameters

Motes self-organize themselves according to IEEE 802.15.4; self-organization implies that all motes have the status of an FFD [6]. In our application scenario an ad-hod clustered-tree multihop topology is supported [7]. 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.

Parent and child roles are interchangeable. A child to mote X at some instance may become a parent to mote X. This is the result of changes in network topology as nodes of Cloud B enter, leave or move in respect to Cloud A. The phase 1 route formation of Cloud A (IEEE 802.15.4 Cluster - tree) is stored as the default status in every mote. Information regarding children and the parent is stored on the motes to be utilized by “upper layers”.

3.2 Phases 2-4: Operation Phases

Once Phase 1 is completed and Cloud A is set to normal operation, Cloud B nodes will associate themselves with that network as sinks. In phases 2-4 of operation, where at least one node is associated with the network we witness the following types of motes at a given instance:

- Hop 0 motes: motes with a neighbor node
- Childless motes: motes without any children; all phase 1 sink motes and all phase 1 childless motes that are not hop 0 motes and only these fall in this category

- Parent/ child motes: motes that have both a parent mote and one or more child motes.

Each mote maintains a look up table of available nodes (nodes in range). As nodes advertise their presence (or leave) the lookup table is updated. The node that serves as a parent to a mote is not part of the table. Whenever more than one nodes are available the look up table contains the Presence Entry information of all of them except the parent node.

3.3 Presence Information

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 (figure 1). All subsequent nodes will form independent clusters. The coordinator could act as a Cloud C gateway as well; other nodes may also act as gateways, that may act as cluster heads or not. The coordinator role may be transferred between nodes.

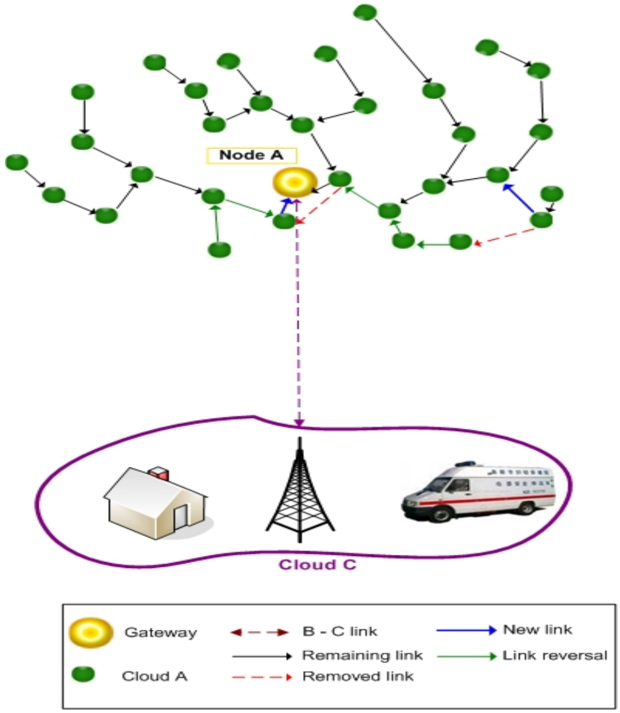

Fig. 1. Phase 2; Network in its infancy

3.4 Clustering

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. In case any of these motes has a 2 or higher hop distance, they transverse their traffic to the mote in question. It may be that the parent of this mote will now become its child (figure 2). 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 broke 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 occurs a new clustered tree network topology is formed.

4 Discussion

Various routing algorithms have been proposed for WSNs [8]. Among them the Minimum Energy Routing and the Minimum Hop Routing suffer from different inefficiencies, the main ones are that they deplete energy in certain frequently used routes and create congestion. Our assumption is that in our application scenarios all motes are equally important and share the same (energy and storage) characteristics.

Homogeneous approaches are closer to our needs. These mostly work by applying a probabilistic choice of the route to use (or the mote to send the next packet) over a set of routes or motes calculated or determined as of least power consumption or over minimizing a metric like residual battery life. All such approaches consider the network as a general purpose network. WSNs however usually do not fit into that rule; they tend to be application dependent, (almost) unidirectional and of predictable rate and thus data flow. In other words, WSNs tend to be (almost) deterministic, as opposed to general purpose (wireless) nets. This is particularly true for medical WSN application, where each measurement is usually equally (critically) important, but information regarding data type and flow is predictable to a high degree.

Application - based protocol design has been studied mostly for the case of cooperation schemes where measurements are inter-correlated and thus redundancy exist [9]. Our scenarios focus on independent measurements. The uncertainty in our case is "controlled" by the (moving) nodes of Cloud B. So at every transmission instance the mote (of Cloud A) has to find the shortest path to the Cloud B, i.e. to the "closest" node of it.

We define presence as a new way of routing. This approach has recently been demonstrated successfully in a mobile peer-to-peer network setting [10]. Presence information identifies a node or a mote in terms of its participation in a route (tree) in a sensor network.

However, our problem is different from the one in there in various terms:

- Only (cloud B) nodes are mobile
- Only (cloud A) nodes transmit genuine information (nodes only retransmit)

- Broadcasting is not required (at least for data transmission)
- State information about a node or a mote does not contain application or user information; rather the status and it contains type.

Thus, our solution focuses on exploiting the collaboration of the two networks, achieving lower network formation traffic.

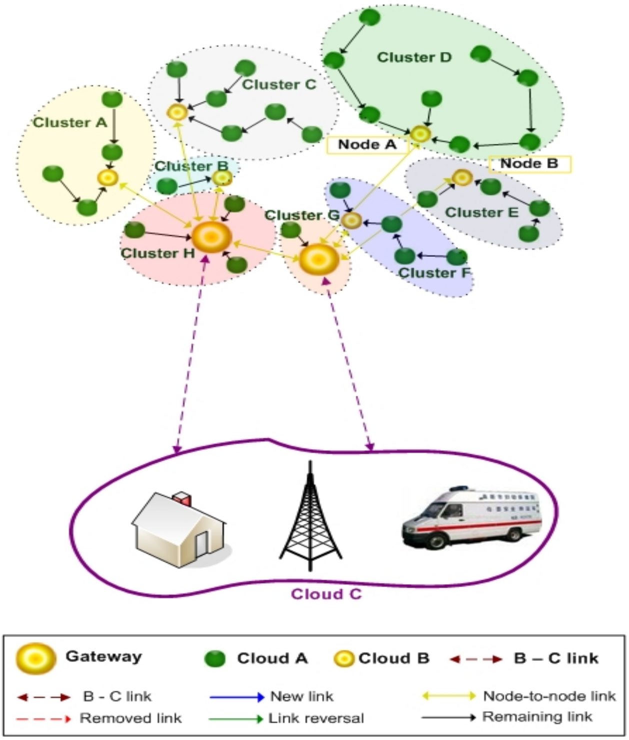

Fig. 2. Phase 3&4; Structured Network and maturity

Another routing algorithm that resembles ours is Low-energy adaptive clustering hierarchy (LEACH) [11]. LEACH adopts a hierarchical approach to organize the network into a set of clusters. Each cluster is managed by a selected cluster head. Simulation results show that LEACH achieves significant energy savings. However, this is only achieved if certain assumptions are valid; these assumptions may evolve to become shortcomings. For example, the assumption that all nodes can reach the base station in one hop may not be realistic, and the length of the steady-state period which is critical to achieving the energy savings may not be suitable for particular applications. Our protocol overcomes these shortcomings by introducing application layer information in the decisions. For example, the rotation of cluster heads appearing in LEACH in order not to exhaust specific motes is irrelevant to us, as the Cloud B nodes are exploited. Furthermore, the steady state period is irrelevant of the protocol and is only dependent on the application features. Finally the cluster tree topology adopted is a direct expansion of the LEACH protocol. Note, 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 [12].

The network formation protocol described here resembles also 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 and efficiency and have the drawback that it becomes a single point of failure and a target for security attacks [7]. However, we overcome this drawback by introducing the Cloud B cluster heading instead of a single Cloud A mote. To the best of our knowledge, this is an improvement appearing here for the first time in literature.

5 Conclusion

Costs and effort required for deploying and maintaining a medical sensor network in a rural undeveloped area, have to be justified. There must be a demonstrable and quantified benefit for all participants involved. Quantification examples range from minimizing the required personnel to operate a system, or the required (technological) literacy, to improving the accuracy of an information retrieval service, not to mention realizing a function that would not be possible using other available technology. A wireless sensor network can only be helpful if there is a substantial need.

Therefore, many of successful developed countries applications (e.g. smart aeration and lighting control in apartments, extensive traffic monitoring in large urban areas, or supply-chain monitoring) are ruled out because they lack a broad need in developing countries. A requirements analysis is necessary, albeit a localized one as what is in need in an area may not be the case in another one.

Nonetheless, wireless sensor devices turn out to have a well-suited potential for many application areas in less developed countries. Because of their self-organising characteristics and robustness, wireless sensor networks can be deployed in less benign environments and inaccessible places as well as in places where employing humans is difficult or costly. Although back-end communication infrastructures are needed to interface wireless sensor networks with the Internet or a local area network, they can also function in the absence of any communication infrastructures. This makes them particularly attractive for developing countries where the presence of stable communication infrastructures as a prerequisite for deploying computing systems may not be feasible.

Today, a wireless sensor network is almost the only ICT means we have that can operate independent of any external communication infrastructure or/and electricity network. The CLAP initial results show promising potential in this area. In the near future we are planning a pilot roll-out of the system in a developing country to test it in an actual setting. Different possible candidates are currently being reviewed, many of which are OLPC villages.

Acknowledgements

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