Agent-Based Clusters to Virtually Manage Spatially Distributed Sensors

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1. Introduction

Spatially distributed monitoring systems have been used in a wide variety of applications over several decades. These systems are conventionally structured with a collection of stationary nodes. Where short-range, self-managed wireless communication is being used (e.g., radio-frequency modems), the problem of setting up the communication network is relatively straightforward for conventional systems. Once the network is deployed, some adjustments may be made to improve communication. However, once communication is reliably established, things don't really change much after that. In emerging Wireless Sensor Networks (WSN), including Sensor Webs, a 'deploy and ignore' approach is no longer possible. Indeed, the conventional 'built-in' station is replaced by a large number of lower-power motes which often conserve their resources by having sleep/wake cycles. In addition, in mobile data collection, communication pathways and network topologies regularly change. Consequently, monitoring must be actively and continually updated. Especially in remote areas where manual maintenance is nearly impossible, monitoring must be carried out by the network in a way that it can detect events of interest and self-configure quickly and efficiently in order to collect and forward data to sinks. The use of clusters during WSN self-adaptation is beneficial for data collection, routing protocols, dealing with uneven distributions of sensors, and increasing sensors lifetimes (Ulmer 2007). In mobile or mote-oriented applications, no efficient solution is yet available for forming clusters by collaborating sensors. This paper summarizes an agent-based clustering approach to virtually manage WSN. It discusses how this approach can be used to self-adapt spatially distributed networks using the context of water resource monitoring.

2. Clustering in distributed sensor networks

Several works address WSN self-adaptation by clustering the network. Clusters that may be formed, for example, by using sensor signal changes (Wokoma et al. 2004) or finding *d*-hop dominating sets (Amis et al. 2000) can be merged to form groups (Chevallay et al. 2002). (Gerla and Tsai, 1995) extended the early Linked Cluster Algorithm (Baker and Ephremides, 1981) to create a multi-hop wireless network suitable for real-time traffic. Gholampour and Shiva (2005) and Pan et al. (2003) proposed two-tiered architectures to control the WSN topology. Wokoma et al. (2005) presented a biologically-inspired clustering approach. Olariu et al. (2004), Van Dyck (2002), and Britton and Sack (2004) used WSN clusters for energy efficiency, performance detection, and environmental applications respectively. All these works focus on sensor-level enhancement. Particularly due to the limited processing capabilities of sensors and associated motes, they still lack efficiency, autonomy, and flexibility to adapt properly to changes in network topology and to set up reliable communication pathways. To meet these goals, it is worth exploring the conception of clusters (Chevallay et al. 2002).

3. Our logical cluster model

The hierarchical model of our virtual wireless sensor network (VWSN) comprises 4 levels: *atom*, *micro*, *meso*, and *macro* (Figure 1). An atom level refers to a single sensor that manages the subspace in its transmission range. A micro level refers to a group of sensors connected to a given mother-pod. The mother-pod, called the level *headmaster*, manages the cluster's sensors and has authority upon their behaviors and processing priorities. Several micro levels may be grouped into a single cluster according to their locations, current capabilities, and connections. A headmaster is elected for the management of this cluster, called a meso level. Conceptually, a meso level may encompass several serial, parallel, or nested meso levels. This configuration changes due to new events. The meso levels taken together represent the entire WSN. They form the macro level of our VWSN hierarchy. The atom, micro, meso, and macro levels are called *logical clusters*. These levels also refer to sub-areas sensed by clusters of sensors.

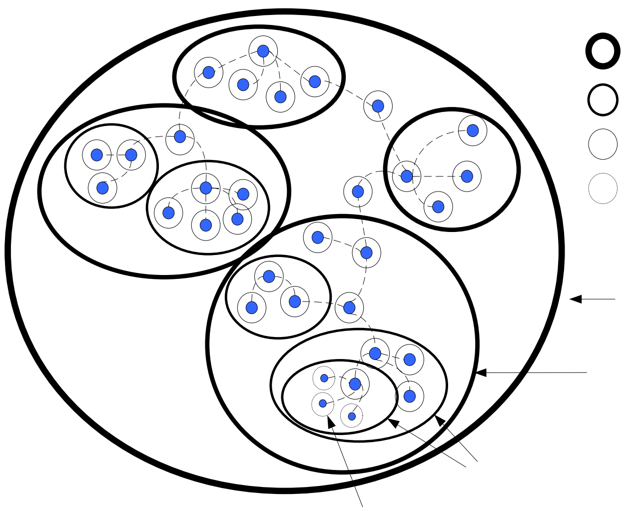

Figure 1.VWSN clustering levels.

4. Setting up the agent-based virtual network

Our virtual network uses a multi-agent system (MAS) (Huhns and Stephens, 1999) that virtually manages the WSN by sending tasks to sensors and processing their collected data. As per our VWSN hierarchy, we assign the software agents *System-Manager-Agent* (SMA), *Virtual-Meso-Area-Manager-Agent* (VMAMA), *Virtual-Mother-Pod-Agent* (VMA), and *Virtual-Sensor-Agent* (VSA) to headmasters managing macro, meso, micro, and atom levels respectively. Except for SMA, VMAMA, VMA, and VSA are assigned to sensors called PMAMA, PMA, and PSA respectively. Thanks to their easy access to available data, agents enhance sensors' context awareness and decision making capabilities.

To deal with new requirements, the SMA identifies the areas of interest according to their contents (targeted data, sensors) and locations (position regarding targets and tasks/data communication pathways). Using a spatial grid, the SMA marks out the bare minimum clusters currently able to sense specific geographical areas of interest. Agents assigned to every cluster self-configure, elect a headmaster (VMAMA), and assign roles to sensors. Several neighbor VMAMAs may negotiate to merge their clusters and create data concentration points. If two clusters are close but not enough to communicate, their VMAMAs must determine bridge sensors that connect both clusters. Additional sensors are used as gates to connect the VWSN and WSN. We assign a Virtual Bridge Agent (VRA) and a Virtual Gate Agent (VGA) to every bridge and gate sensor respectively. The VMAMAs, VMAs, VSAs, VBAs, and VGAs form the VMN that controls current WSN processing.

5. Relation to the physical sensor network

Before data acquisition begins, agents send *set-up messages* to their sensors. These messages contain sensors' roles, neighbors, transmission ranges, gates and relays locations, schedule, and lowest-cost paths to send data to the VWSN. Using this information that may change as time goes by, sensors self-configure to create physical clusters and to set up the physical monitoring network (PMN) (Figure 2). Every headmaster-sensor tests the connectivity of its cluster by sending *ping messages* to its sensors. When *acknowledgements* are received, the headmaster-sensor sends a *report message* to its agent using the lowest-cost path.

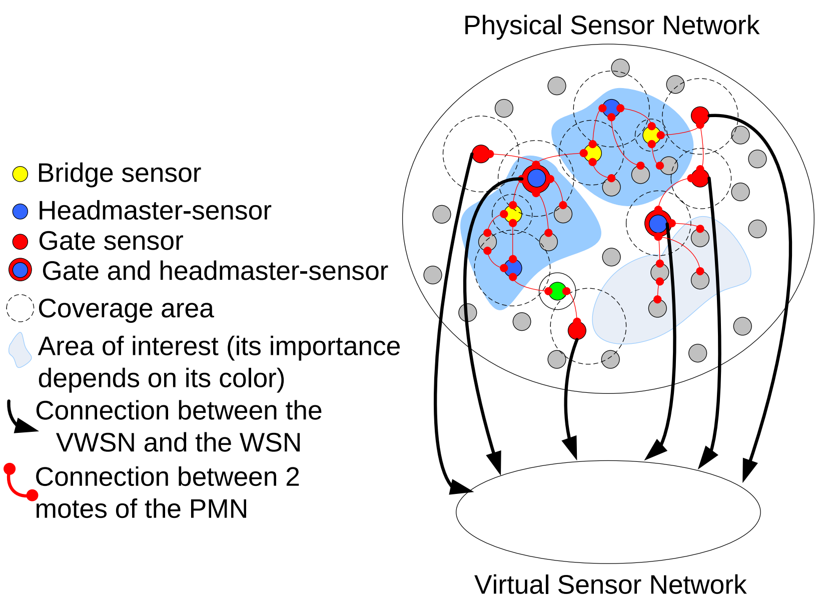

Figure 2. PMN set-up.

6. VWSN for water resource monitoring

When rain falls in abundance, the SMA determines the required subnets to collect data from strategic locations on the landscape (e.g. headwaters and beside water bodies in gently sloped terrain). Once the VMN and PMN are set up, every sensor collects data according to its schedule. This data is forwarded to the target (PMAMA, PGA, etc.) specified in its set-up message. Headmaster-sensors analyze the collected data and update their subnets processing priorities notifying each other of any worrying water level or flood risk. Using its augmented knowledge, which can be derived from GIS data or analysis in more advanced applications, a given sensor shifts its data to the next sensor of the lowest-cost path to available PGA. This path is identified using the set-up message and any change notified by neighbor PMAMAs, PRAs, and PGAs. Mobile sensors may move in order to reduce their transmission costs. During data forward, sensors acknowledge to each other the messages received. Once data is received from the WSN, it is analyzed by the appropriate agents (sinks). If data analysis reveals a flood risk, sinks warn the SMA that makes the relevant decision (orders agents to change their sensors' schedules, activates new sensors for better data acquisition, alerts the user to evacuate specific areas or deploy barriers, etc.). Decisions taken by agents are sent as new tasks to appropriate sensors through gates.

7. Conclusion

We proposed an agent-based clustering approach to virtually manage a spatially distributed WSN. Our approach identifies geographic areas of interest as well the bare minimum logical clusters currently able to answer the environmental requirements. In order to adapt to network topology changes and to set up reliable communication pathways, these clusters are sent to sensors that self-configure into physical clusters, forming a physical management network. Thanks to their easy access to available data, our agents enhance sensors' information accuracy, context awareness, and decision making capabilities. These enhancements are particularly beneficial for mobile sensors. Moreover, seeing the current limited capabilities of sensors, our approach may lead to an interesting discussion concerning virtual management of spatially distributed sensors. Our future work will focus on examining how the VWSN can have direct interaction with geosimulation or spatial decision support system tools. Such coupling could possibly create convergence between the physical, geographic structure of the sensor network and the logical, topological structure of the communication network management.

8. Acknowledgements

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