TOWARDS INCREASING THE REUSABILITY OF THE WIRELESS SENSOR NETWORK PROTOCOLS

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Abstract: Increasing the reusability of the wireless sensor network protocols requires decoupling the underlying communication primitives from the upper layer protocols primitives. One way to achieving this goal is unifying the whole software stack architecture. This unifying process would significantly increase the overhead and affect the resulting performance. It is still unknown whether this huge unifying process will provide the required benefits to the protocol designers. Building a generic infrastructure at the level of physical links is a promising step towards increasing the reusability of upper layer protocols. To be described as a generic, the infrastructure should efficiently support different upper layer protocols and different communication configurations. It should also provide logical relationships among nodes without hiding the physical relationships. Moreover, Failures should neither destruct the infrastructure nor hinder the upper layer operations. Building such infrastructure is very challenging and is still an open research problem.

1 INTRODUCTION

The random deployment process in wireless Sensor network WSN results in an arbitrary network graph that is referred to as a network topology (Akyildiz 2002); communication over such a graph is secured via multiple hops. This mode of communication implies that each node is able to play the role of a router, and thus forward the messages over multiple hops on behalf of other nodes—the arbitrary topology graph is structured by the communication algorithm (Yoneki and Bacon, 2005). The communication process then takes place through the primitives of the communication algorithm;

Most of the current proposed protocols for WSN are described as cross-layered protocols (Wu 2007), which reflects the fact that these protocols are in most cases tied up to specific communication algorithm which is optimized for a specific network deployment. For example, spanning tree based algorithms opt for building the tree structure over the arbitrary graph. Then the communication process takes place using the tree primitives.

Decoupling the communication protocols from the application semantics to increase the modularity and reusability is still an open research direction that should be carefully studied. Given that the sensor network is mainly application oriented, the benefits of the clear cut between various networking aspects over the current cross- layer approaches require more research efforts to be clearly identified. To date, little work has been conducted towards unifying protocol design.

2 PROTOCOLS REUSABILITY

One of the research concerns that is not fully explored in the literature is the degree of independency between various network protocols. Most of the current proposed protocols merge functions from different networking levels. To date, little work has been done towards unifying the design of WSN protocols. WSN is application-specific in the first place. It poses many challenges that motivate the production of hundreds of protocols at each networking level. The different hardware characteristics and the different requirements of the upper layer applications boost the protocol productivity of WSN (Whitehouse et al. 2004).

Numerous protocols that target aggregation,

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routing, dissemination, medium access and topology control have been developed. The main notice regarding the wide scope of WSN protocol development is that the performance of a given protocol is tied to the underlying assumptions about the rest of the system. When such assumptions are varied, degradation in performance is noticed. The variety of possible assumptions about the system decreases the reusability of the developed protocols.

A new research direction towards unifying WSN software architecture that increases the modularity and reusability of the designed protocols is established in (Culler e al. 2005; Cheng et al. 2006).

In (Culler et al. 2005) the authors discuss the narrow waist architecture where sensor protocol (SP) resides between the network layer and the data link layer. They describe the rules by which the network services could be arranged over the layered architecture. They also discuss the neighbour's management issue.

Leveraging the SNA (Culler et al. 2005), a modular network-layer for sensor networks that sits atop SP is proposed (Cheng et al. 2006). Their main concern is to ease the implementation of new protocols by increasing code reuse and runtime sharing. Code reuse provides a rapid protocol and application development. On the other hand, run-time sharing reduces code and resources consumed. The authors discuss the trade-off between functionality decomposition and complexity. They find that finding the right granularity at which to break up the functionality at the network layer is challenging. Unnecessary runtime overhead could result from a very fine-grained decomposition while a too coarse decomposition reduces the level of sharing, which in turn increases the reimplementation.

Gnawali (2006) proposes Tenet architecture, which is complementary to the narrow waist architecture proposed in the work of (Culler et al. 2005). Tenet architecture does not address the modularity of the software. It restricts the placement of the application functionality in a multi- tier system. In Tenant, the sensor level tier can be implemented on SP. Tenet shares some similarities with the Internet's end-to-end principle (Saltzer et al. 1984), yet it is based on specific tiered network technology.

The above solutions target achieving complete standard software stack architecture for sensor networks. This is still far away from being a reality. There is a conviction in the literature that this unifying process would significantly increase the overhead and affect the resulting performance (Ali and Langendoen, 2007). It is still unknown whether this huge unifying process will provide the required benefits to the protocol designers.

Building a generic infrastructure at the level of physical links is a promising step towards increasing the reusability of upper layer protocols. To build such infrastructure over sensor networks, the literature explores two approaches; the first is to construct an in-line infrastructure that supports a specific process, such as routing or data aggregation. This model is usually optimized to efficiently achieve an upper goal such as minimizing congestion. Clustering and tree-based approaches are the most utilized techniques to build such infrastructure. They provide nodes with the means to self-organize and thus achieve unstructured overlays (Younis et al. 2006). Operations over such overlays are usually based on flooding mechanisms (Olariu et al. 2004); failure handling and maintenance require cascade updates throughout the network. In addition, the resulting infrastructure cannot be utilized by different protocols.

The second approach is building an infrastructure that is not tied to any upper protocol. This is a general purpose infrastructure, which should be able to support different upper layer processes with equal efficiency. To be generic, we claim that the infrastructure should adhere to the following design objectives:

(i) **Generic**: efficiently supporting different upper layer protocols (e.g., routing, data collection, data aggregation and broadcasting).

(ii) **Flexible:** efficiently supporting different communication configurations (both multi- hop and data mule- like communication).

(iii) **Maintainable**: failures neither destruct the infrastructure nor hinder the upper layer operations.

(iv) **Complete**: providing logical relationships among nodes without hiding physical relationships.

Taking into consideration that sensor networks are application-oriented and have scarce resources, the problem of building such generic infrastructure is challenging.

Building generic infrastructure over sensor networks is studied in (Olariu et al. 2005). The authors develop a virtual infrastructure in terms of coronas and wedges. They consider the case of a static sensor network where all nodes are static. The sink, named as Training Agent (TA), is assumed to be at the centre of the network, and it is assumed that the TA has multiple-levels transmission range. The TA takes the burden of training the nodes to acquire knowledge about their position with respect to it (TA). The position is considered as the (wedge, corona) where the node is located; however, the protocol is centralized and is based on global information. The number of coronas to be created should be known to the TA before it creates them. In addition, the mechanism proactively divides the nodes into subsets and requires synchronization of the wakeup times of each subset of sensor nodes and the level of the transmission range of the sink at that time. This model is extended to account for the TA's mobility in (Olariu et al. 2007). Mobility is considered for achieving the QoS requirements of the applications rather than for infrastructure organization. Moreover, the authors do not specify the effects of involving multiple sinks/TAs on the constructed infrastructure. For example, how to proactively determine the number of coronas per each TA is not answered.

A multi-scale communication overlay is developed in (Palchaudhuri et al. 2005) to support upper layer protocols. The protocol belongs to the clustering-based approaches. Nodes are organized into cells, super-cells and so on. A self-election mechanism based on sending periodic beacons is used to form the hierarchical overlay. As in most clustering based approaches, maintaining the whole structure requires topological updates to be broadcasted to all nodes, and re-clustering is performed to adapt to the changes. This introduces extra overhead that could participate in draining the resources of sensor nodes.

Building logical overlays, such as Distributed Hash Tables DHTs, has long been the focus of research. Sensor nodes have scarce resources in terms of energy, bandwidth and communication, which render DHTs unsuitable; the main reason being the belief that DHT overlays produce extra overhead compared to the benefits they provide to the upper layer applications (Ali and Langendoen, 2007). When mobility is considered, movement of the nodes may quickly change the topology, thus resulting in an increase in the overhead messages for topology maintenance and movement management.

An attempt to fill in the space between the logical and physical infrastructure is proposed in (Caesar et al. 2006). Authors proposed a Virtual Ring Routing (VRR) protocol where logical rings are constructed over the link layer. The protocol is inspired by DHT mechanisms, and provides both point-to-point and DHT like operations. The protocol creates logical rings that do not keep the node proximity. Moreover, all nodes within the network should have unique logical addresses (identifiers) that are globally ordered. In addition, the protocol is optimized only for routing processes.

A promising approach for building a generic infrastructure that adheres to the design objectives mentioned above has been proposed in (Hashish and Karmouch, 2009). The authors proposed Layered Infrastructure Protocol (LIP). LIP exploits mobility to organize sensor nodes, and form a generic flexible infrastructure that could be leveraged by upper layer protocols. LIP allows mobile robots/sinks to discover *physical* co centric circular layers within the arbitrary network topology. LIP creates *physical* co centric circular layered infrastructure (CLI)-the resulting CLI infrastructure guarantees the proximity of the nodes. Nodes that are neighbours in the infrastructure are physically neighbours; each layer in CLI is assigned a mobile robot that acts as a probe to access the data and monitor the layer. Access positions are selected dynamically at each layer to act as anchors for the probes to visit at their associated layers.

CLI has the ability to trade mobility overhead vs. communication overhead (higher number of access points implies that data travels in smaller number of hops to access points, hence to be offloaded to the moving robot/sink). Moreover, layers in CLI are managed separately by the associated mobile robots. This makes CLI a rich environment for developing efficient upper layer protocols (Hashish, 2010). It provides varieties of communication configurations which support both multi-hop and data-mules regimes of communication. It also provides a high degree of reliability to the upper layer applications while reducing the overall energy consumption. This ability to cope with failures makes it a good candidate for sensor networks applications; Applications based on adaptive allocation of mobile sinks, applications based on nodes scheduling and applications based on multi-granularities communications could be efficiently developed atop of CLI.

3 CONCLUSIONS

In this paper, we show that decoupling the communication protocols from the application semantics to increase the modularity and reusability is still an open research problem. The main approaches for increasing the reusability of the wireless sensor network protocols have been discussed. Achieving standard software stack architecture for sensor networks is still far away from being a reality. Building a generic infrastructure at the level of physical links is a promising step toward increasing the reusability of upper layer protocols. This is very challengeable in sensor networks that feature scares resources. Some of the existing solutions and their limitations have been described. Limitations of the existing solutions have been mentioned.

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