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AUTONOMIC WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless ad hoc networks of sensor nodes are envisioned to be deployed in the physical environment to monitor a wide variety of real-world phenomena. Wireless sensor networks (WSN's) are becoming popular in military and civilian applications such as surveillance, monitoring, disaster recovery, home automation and many others. Almost any sensor network application requires some form of self-configuration and autonomic functionality. Following IBM's initiatives towards Autonomic computing many architectures and protocols for network self-organization and management have been proposed and being implemented.

The paper presents concept of Autonomic Computing with respect to Wireless Sensor Network. The paper introduces Wireless sensor network basics, design goals and challenges along with current and future applications. It articulates basic needs of incorporating autonomic computing principles into the design of Wireless Sensor Networks. The paper also outlines recent contributions to Autonomic network architectures, research projects, proposed architectures and routing protocols for Autonomic Wireless Sensor Networks.

INTRODUCTION

Wireless sensor networks have critical applications in the scientific, medical, commercial, and military domains. Examples of these applications include environmental monitoring, smart homes and offices, surveillance, and intelligent transportation systems. It also has significant usages in biomedical field. As social reliance on wireless sensor network technology increases, we can expect the size and complexity of individual networks as well as the number of networks to increase dramatically.

Wireless sensor networks are typically used in highly dynamic, and hostile environments with no human existence (unlike conventional data networks), and therefore, they must be tolerant to the failure and loss of connectivity of individual nodes. The sensor nodes should be intelligent to recover from failures with minimum human involvement. Networks should support process of autonomous formation of connectivity, addressing, and routing structures. Recent researches on Autonomic Networking can serve as basis for design of *Autonomic Wireless SensorNetworks*.

The paper introduces Autonomic computing and wireless sensor network concepts. Discusses how the fundamental properties of Autonomic computing comply with the basic design requirements for wireless sensor networks. Proposed protocols for Wireless Sensor Network and their applicability and suitability to Autonomic Wireless Sensor Networks and required improvements. The paper gives brief overview of research projects and architectures for autonomic communication and networking which can be applied to WSNs. The last section focuses on the current and possible future applications of Autonomic Wireless Sensor Networks

AUTONOMIC COMPUTING

Background

The dramatic increase in computing devices, increased computing capacity and complexity combined with popularity of internet resulted in phenomenal growth in heterogeneous networks and network applications. With this increasing system complexity, network management issues and communication protocols are reaching a level beyond human ability to manage and secure so the stability of current infrastructure, systems, and data is at an increasingly greater risk to suffer outages and general disrepair. Future network algorithms need to be adaptive, robust, and scalable with fully distributed and self-organizing architectures. Automation, self-protection and self management of wide spread networks may solve the problem till someextent.

As the concept of self management rooted up, the most direct inspiration one can think of was the *autonomic function of the human central nervous system,* where autonomic controls use motor neurons to send indirect messages to organs at a sub-conscious level. These messages regulate temperature, breathing, and heart rate without conscious thought. Observation and analysis of these complex adaptive systems found in nature became a major source of inspiration to design algorithms for self-managed, self-organized, self-configuring and self-protecting systems.

Taking inspiration from autonomic nervous system of the human body IBM created a foundation for autonomic systems by taking initiatives towards Autonomic Computing for relieving humans from the burden of managing computer systems which is growing enormously till the extent of unmanageability.[01]

Autonomic System

Autonomic System is a system which works independently on predefined policies and rules without any human interaction and manage and configure itself on its own based on predefined rules and gained knowledgs over the time. IBM has defined the following four functional areas for self management of Autonomic System: (Ref [03])

Self-Configuration: Automatic configuration of components.
Self-Healing: Automatic discovery, and correction of faults.
Self-Optimization: Automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements.
Self-Protection: Proactive identification and protection from arbitrary attacks.

IBM Autonomic Computing architecture

IBM Autonomic Computing Architecture [02] defines an abstract information framework for self-managing IT systems. In the information framework, an autonomic system is a collection of autonomic elements. Each autonomic element consists of an autonomic manager (AM) andthe managed resource (MR). The communication between the AM and the MR is done through the MR‟s management interfaces, which exposes two types of hooks, sensors and effectors. The sensors are used by the AM to obtain the internal state of the MR, and the effectors are used by the AM to change the behavior of the MR. The AM enables self-management of the resource using a „„„monitoring, analysis, planning, and execution‟‟‟ control loop, with supporting knowledge of the computing environment, management policies, and some other related considerations.

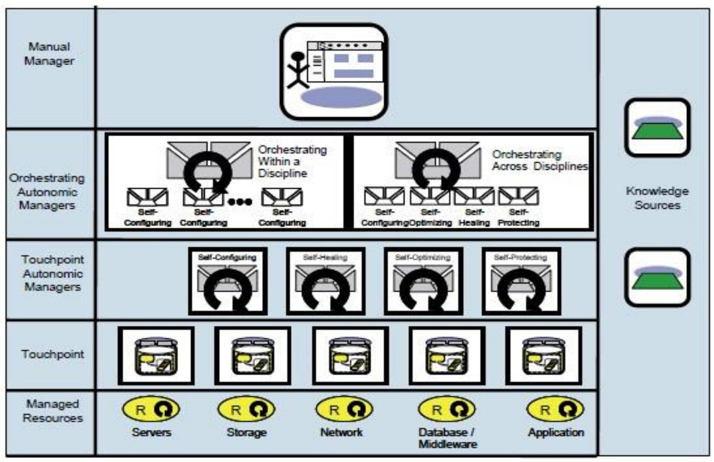

Figure 1. Basic Autonomic Computing Reference Architecture
(This is figure is taken from IBM Autonomic Computing architectural Blue Print [02])

The autonomic computing information model only provides the conceptual guidance on designing self-managed systems; in practice, the information model needs to be mapped to an implementable management and control architecture for Autonomic Networks. Specifically, measurement techniques, rule engines, planning methodologies, dynamic resource allocation techniques, security and management schemes need to be developed for autonomic elements, and a scalable management platform is required to coordinate the autonomic elements into a self-managing system.

WIRELESS SENSOR NETWORK

A wireless sensor network (WSN) is a network that is made of hundreds or thousands of sensor nodes which are densely deployed in an unattended environment with the capabilities of sensing, wireless communications and computations (i.e. collecting and disseminating environmental data). These spatially distributed autonomous devices cooperatively monitor physical and environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. The basic archetecture of Wireless sensor Network is shown inFigure2.

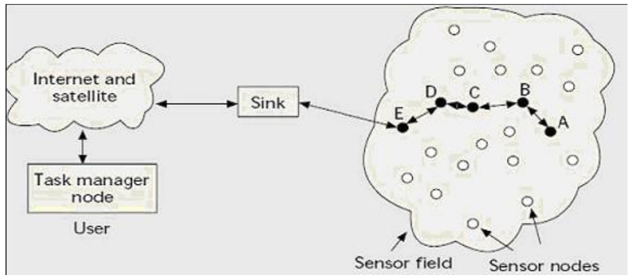

Figure 2. Basic Architecture Of Wireless Sensor Network. (Ref [04])

Each autonomic node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a processing unit which can be a small micro-controller, sensing unit, and an energy source, usually an alkaline battery. Sometimes, a mobilizer is needed to move sensor node from current position and carry out the assigned tasks. Since the sensor may be mobile, the base station may require accurate location of the node which is done by location finding system. The size of a single sensor node can vary from shoebox-sized nodes down to devices the size of grain of dust.[04]

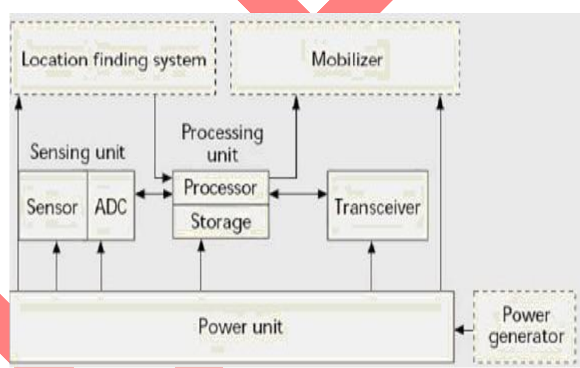

Figure 3. Components of a Sensor Node (Ref [04])

Requirements and Design factors in Wireless Sensor Network–

Following are some of the basic requirements and design factors of wireless sensor network which serve as guidelines for development of protocols and algorithms for WSN communication architecture.
1. Fault Tolerance, Adaptability and Reliability: Sensor networks are required to operate through adapting to the environmental changes that sensors monitor. The networks should be *self-learning.* Reliability is the ability to maintain the sensor network functionalities without any interruption due to sensor node failure. Sensor node may fail due to lack of energy, physical damage, communications problem, inactivity, or environmental interference. The network should be able to detect failure of a node and *organize* itself, *reconfigure* and *recover* from node failures without loosing any information. [05]

2. *Power Consumption and Power management*: One of the components of sensor nodes is the power source which can be a battery. The wireless sensor node being a microelectronic device, can only be equipped with a limited power source [04]. Over the remote inaccessible place with less human control and existence, power sources play critical role in survival of sensor nodes. Power source should be intelligently divided over sensing, computation, and communications phases as per requirement. Sensors can be hibernated when inactive. Lots of current researches are focusing on designing power-aware protocols and algorithms for wireless sensor networks. Recently, solar energy is also considered as an option for empowering remote sensor nodes which are exposedenvironment.

3. *Network Efficiency and Data Aggregation*: Flooding raw sensed data over the network can easily congest the network. Some critical applications like *intruder detectors* require urgent transmission and faster processing of data which may degrade performance and loose reliability due to congestion or latency in the network. Intelligent aggregation of sensed data and elimination of unwanted and redundant information and data compression can be a solution for efficient resource and energy utilization and congestion avoidance. Many algorithms like directed diffusion [06] are proposed to facilitate data aggregation and dissemination within the context ofWSNs.

4. *Intelligent Routing*: In many applications, sensor nodes are moving nodes and can change place dynamically. Routing protocols must be adaptive to these changes and should be *self-healing* and *self-configuring*. The information should be persistent in spite of changes in network nodes. Low processing capacity of a node creates many challenges for routing packets throughout the neighbouring nodes intelligently. As discussed above, some applications may require a faster communication and instant response. Routing algorithms should be intelligent to choose minimum hop and minimum distance paths for data transfer.[07]

5. *Management challenge* – Managing the communication over heterogeneous networks is basic challenge in self-managed system because policies and communication protocols plan an important role in network communication. Also, it is necessary to balance the level of detail the network is providing to the client against the rate at which energy is being consumed while gathering the data. Clearly, it is preferable to have the network automatically do this tuning, rather than requiring manual intervention.

These basic requirements and design goals serve as challenge for current technology. Though current IP routing protocol exist and have significant applications in current networks and Internet, they do not satisfy complete design requirements in Wireless sensor networks because WSN nodes typically has limited computing capacities and less power. So WSN"s require a different infrastructure and protocol stack which can be implemented using autonomic computing concept as we will discuss in next section.

WIRELESS SENSOR NETWORKS AND AUTONOMIC COMPUTING

To clarify the contribution that autonomic computing can bring to Wireless Sensor Networks (WSN), let"s examine how WSN design requirements and operations can be tackled using autonomic principles.

As discussed above, there can be sensor nodes which are moving and can change their position dynamically or even leave the network coverage area. Therefore, a pre-programmed configuration for the network will not work. **Self-configuring** nodes can set up network connections, evaluate if there are any gaps in the WSN and replace a moved or dead node in the network. Since sensors can be deployed in an unattended area (e.g., forest and ocean) or physically unreachable area (e.g., inside a building wall), they are required to operate with the minimum aid from base stations or human administrators. Although majority of current sensor application have already considered this in their network design, there is still a need for WSN to have the ability to reconfigure and recover itself without too much human intervene, especially in inaccessible environment. [04, 05]

Sensor reading usually contains some noises; it may be a false positive due to malfunction of sensors. Sensors are required to collectively **self-heal** (i.e., detect and eliminate) false positives in their sensor readings instead of transmitting them to base stations. This can also reduce power consumption of sensors because data processing within the sensor incurs much less power consumption than data transmission does [10].

Sensor nodes are generally exposed to much harsher conditions than standard computing equipment, and are thus subject to energy depletion and incidental damage. Battery failure can result in lost sensor node. This leads to a gradual degradation of the network as individual nodes are lost. Network paths break and gaps appear in the coverage area. A WSN needs to adapt to the changes, recover from losses and be **self-protected**. This can be achieved by renegotiating network routes, monitoring voltage levels within sensor node, controlling each node by an agent or base station and upon failure activating redundant nodes to replace damaged ones, or by informing some higher-level entity which can provide assistance.

As discussed in requirements, maximum efficiency needs to be gained from the available energy as the available energy at each sensor node is limited. Sensing, Processing and data transfer phases require lot of energy so each node should be able to sense process and transfer data intelligently hence **self-optimization** is an important trait for WSN protocols. Energy savings can be achieved by putting the nodes into a low power sleep mode, ready to be reactivated when the need arises. For example, sensors may decrease their duty cycles when there is no significant change in their sensor readings. This results in less power consumption in the sensors. Also, when neighboring sensors report environmental changes, a sensor may draw inference from the reports and increase its duty cycle to be more watchful for a potential local environmental change in the future. However, there exists a trade-off in that the computational cost of a globally-optimal solution such as this is often computationally intractable, whether by 8-bit nodes or 64-bitbase-stations.

All basic WSN self-management principles comply with the concept of autonomic computing. So IBM autonomic computing principles can be applied to wireless sensor networks to get the desired functionality in vastly growing sensor network applications.

CONCLUSION

Wireless Sensor Network technology offers significant potential in numerous application domains. Given the diverse nature of these domains, it is essential that WSNs perform in a reliable and robust fashion. I believe, wireless sensor network has proved its usage in the future distributed computing environment. However, there are significant amount of technical challenges and design issues those needs to be addressed. One of the biggest challenges is the designing of efficient network management architecture to continuously support WSNs for providing services for various sensor applications. The unique features of WSNs make the design and implementation of such management architecture different enough from the traditional networks which can be satisfied by concept of Autonomic Computing. There is still no particular generic network management architecture so taking inspiration from IBMs Autonomic Computing concept and Biological neural network system many different research projects are currently being executed.

In this paper, we discussed concepts of Autonomic computing, Wireless Sensor Networks (WSN‟s). Design criteria for WSN and how it matches basic Autonomic principles. Then we overviewed few architectures and routing protocols suitable for WSN and ongoing research work of Autonomic communication and network management architectures which can be applied to WSNs. Finally, we summarized some of the WSN applications along with future usages.

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