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Self-organizing, Wireless Sensor Networks

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As a result of significant advances in micro-electro-mechanical systems (commonly known as MEMS), low-power, small form factor radio transceivers, and compact digital circuit designs, self-organizing, wireless sensor networks (SOWSN) are becoming a reality in residential, commercial, medical, industrial and military applications. A SOWSN eliminates the need to log sensor-based devices into the network or manually establish the path of network data back to the base station or control center - it automatically routes data transmissions to the appropriate destination. A SOWSN reconfigures itself automatically to respond to changes in the number and location of devices to accommodate additions, modifications and deletions to the number of devices in the network as well as mobile sensor nodes throughout the network.

Wireless sensor networks are now capable of operating with sub-milliampere power consumption, allowing a 3-volt DC coin-sized battery to power a wireless sensor node for periods up to 10 years, depending on the sampling rate. Tiny wireless sensor nodes integrated with a coin battery are portable, unobtrusive, and easily integrated into the smallest devices. Today, these wireless networks are being used in a number of low-power, low data rate applications: transmitting machine monitoring and digital precision instrument data throughout the factory floor, collecting water and gas meter readings, monitoring shipments through the supply chain and reporting on the vital signs of remote health monitor wearers.

All wireless sensor networking applications share three common requirements: small form factor, long battery life and a robust and efficient networking protocol. A very small form factor is needed so that these devices can fit inside or attach easily to an existing device. Extremely low power consumption is required so that small, coin-size batteries can be used for extended periods of time, otherwise frequent battery changes result in high support and maintenance costs. Finally, a robust networking protocol is needed for low latency, high scalability and high network responsiveness. This last requirement is particularly important for applications where sensor nodes are mobile, such as in mobile machines or equipment or for wearable sensors.

This article examines the different choices for SOWSN topologies, while future articles will discuss the challenges associated with sensor node size (sensor plus transceiver), power management, including environmentally powered (vibration, solar and thermal) SOWSN, and the variety of application classes being implemented today for SOWSN technologies.

The topology architectures used to implement wireless sensor network solutions include star, mesh, and star-mesh hybrid topologies. The choice of the appropriate topology depends on the amount and frequency of the data to be transmitted, transmission distance, battery life requirements, and the mobility and level of change in the sensor node.

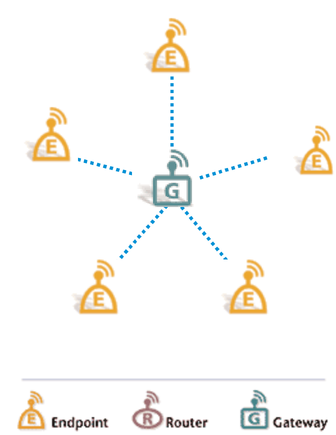

Figure 1. Star SOWSN Topology provides the simplest and lowest power network.

A star topology (Figure 1) is a single-hop system in which all wireless sensor nodes are within direct communication range (usually 30-100 meters) to a base (monitoring) station. The base station can be a PC, PDA, dedicated monitoring device, or other gateway to a higher data rate device. In a star topology all sensor nodes are identical and the base station serves to communicate data and commands to the sensor endpoints, and to transfer data to a higher-level system, such as the Internet. Among wireless networking topologies, the star topology is the lowest in overall power consumption but is limited by the transmission distance of the radio (typically 30 to 100 meters in the ISM band) in each node.

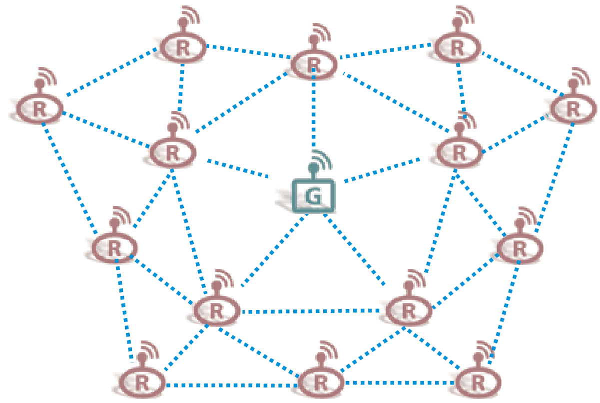

Figure 2. Mesh SOWSN Topology uses routing nodes to extend coverage area and provide fault tolerance with node-to-node hopping. It is also the networking topology with the highest overall power requirements.

Mesh topologies (Figure 2) are multi-hopping systems in which all wireless sensor nodes are identical and communicate with each other to hop data to and from the sensor nodes and base station. Wireless sensors can also pass commands directly to each other in a mesh network, avoiding the need to communicate with each other through a base station. A mesh network is highly fault tolerant since each sensor node has multiple paths back to the gateway and to other nodes. If a sensor node fails, the network will automatically reconfigure itself around the failed node. The multi-hop system allows for a much longer range than a star topology, but has a higher power consumption rate. The higher duty ratio of a mesh network (since sensor nodes need to always "listen" for messages or for changes in the prescribed routes through the mesh), is the principal reason for the high power requirements. Depending on the number of nodes and the distances between them, the network may also experience high latency as sensor data is hopped from node to node on its way to the base station.

A star-mesh hybrid (Figure 3) seeks to take advantage of the low power and simplicity of the star topology, as well as the extended range and self-healing nature of a mesh network topology. A star-mesh hybrid organizes sensor nodes in a star topology around routers or repeaters which, in turn, organize themselves in a mesh network. The routers serve both to extend the range of the network and to provide fault tolerance. Since wireless sensor nodes can communicate with multiple routers, the network reconfigures itself around the remaining routers if one fails or if a radio link experiences interference. A star-mesh network

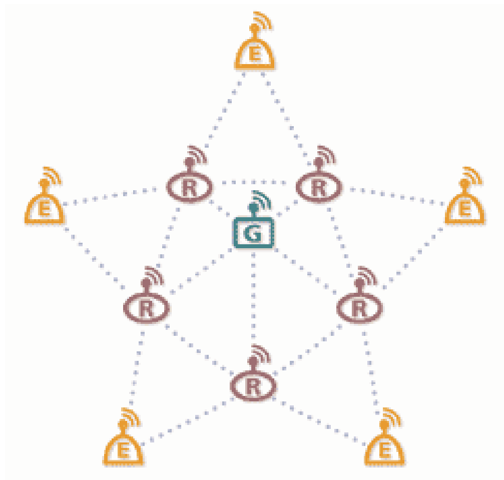

Figure 3. Star-Mesh SOWSN combines a mesh of routers (to extend coverage and route around obstacles) with star endpoints. A Star-Mesh topology combines the benefits of multi-hopping to provide extended reach and fault tolerance with ultra-low power sensor endpoints.

offers the highest degree of sensor node mobility and flexibility for rapid changes to the network population and the lowest overall power consumption for networks that need to stretch beyond 30-100 meters. For these reasons, the star-mesh hybrid is proving to be a logical choice for SOWSN. Using this technology the opportunity to provide better diagnostic data, lower the cost of treatment, and ultimately, improve a patient's quality of life can be realized today.

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