INTEGRATED SENSOR NODES WITH GSM MODEMS: SIMPLIFYING THE TASK OF WIRELESS DATA ACQUISITION

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A sensor network typically consists of a number of sensor nodes which each acquire signals from a sensor or multiple sensors and a system to transmit and process the data acquired from sensors. The sensor nodes can communicate the data within one another or to a centralized location over a wired or wireless network. The sensor network can thus be classified as a data acquisition network and data distribution network. The data acquisition system typically consists of sensors and circuitry to handle the real-world information available and the data distribution network involves the communication protocols, network topology, and methodology to transmit and handle the data. The basic network topologies used are star, ring, bus, and mesh, as shown in Figure 1.

![Network Topologies](image_url)

Figure1. Network Topologies

The choice of the sensor network topology depends upon the application and the kind of processing and data handling required.

Figure2 shows the typical organization of a sensor node. The sensor node consists of:

1. Sensors
2. Conditioning circuitry
3. Microcontroller and associated memory
4. Transceiver (GSM Modem)
5. Power supply
Sensors

The sensors are hardware devices which produce an output based on measurable changes in the physical environment like temperature, pressure, density, and the presence of certain materials. The output of a sensor is generally analog in nature. Sensors should be very small in size, consume little power, be able to be manufactured easily, operate autonomously, and adapt to a variety of operating conditions.

Conditioning circuitry

As the signal received from a sensor is generally very weak, it has to be amplified. In addition, if the signal received from the sensor is alternating in nature, then it must be band limited before it is digitized since signal sampling by an ADC has a direct dependence on the bandwidth of the signal. The signal conditioning circuitry can also help in overcoming environmental factors which affect the accuracy of the system.

ADC

An analog-to-digital convertor (ADC) converts the analog signal received after conditioning from the sensor into a digital signal. Apart from factors like resolution, sampling frequency, and noise immunity, an ADC should consume very little power. The choice of ADC also depends on the kind of processing done after the acquisition of the signal.

Microcontroller

The microcontroller performs the tasks of processing the received data and controls system tasks within the sensor node. The ADC may be internal to the microcontroller. The memory may be internal or external to the microcontroller depending upon the amount of data to be logged. The choice of microcontroller depends upon the power consumption and complexity of the system. For certain applications, most of the processing could be done by the microcontroller. Tradeoffs that should be considered when choosing a microcontroller include active power consumption, stand-by power consumption, and processing capabilities.

Transceiver

The functionality of having a transmitter and receiver combined into a single device is a transceiver. Sensor nodes often make use of wired or wireless media to transmit data to a centralized location or among themselves. The possible
choices for wireless transmission media are standard communication protocols in the ISM bands (Industrial Scientific Medical), namely Bluetooth, Wi-Fi, Zigbee, etc. The wired media includes could include LAN, CAN, etc.

**Power Source**

The microcontroller, transceivers, sensor, and associated circuitry require electrical power. The power supply must be clean so that it does not interfere with the operation of the sensor. The choice of power source depends on watt-hrs and also the density of the power source, i.e., space constraints. Power is a critical issue for sensor networks. Each of the above mentioned parameters are typically optimized for power consumption balanced against system performance requirements.

**Applications of sensor networks**

The application of wireless sensor networks involves monitoring, surveillance, tracking, etc. Telemetry refers to remote monitoring system and is a generic term that can be used for any application that requires monitoring of processes and equipment from a distance. These typically include machine monitoring, animal monitoring, vehicle monitoring, medical monitoring, ship monitoring, etc. A wireless sensor network can be used for such a remote monitoring system of areas that are hard to access. Telemetry finds applications in agriculture, military, water management, sensing of environmental changes, monitoring of pollutants, etc. Wireless sensor can also automate the process of data collection and reduce human error in these tasks. In smart grid systems, the sensor networks could send data from individual locations to enable better management of the grid as a whole. Sensor networks can also be used for monitoring a fleet to gather and report on the position of each individual ship and trace its location continuously. Sensor nodes can also be connected to temperature sensors to avoid any disruption of the cold chain during transport of goods to help to ensure the safety of food, pharmaceutical, and chemical shipments.

**Need of wireless capabilities for a sensor node**

The need for improving connectivity from PCs to the real world is gaining momentum. There are a great many sensor and actuators in use, and interconnecting them by integrating the data available is becoming very important. The numbers of nodes in a sensor network continues to increase and wired connectivity is often not an option since sensors must be placed in remote locations. The cost per node is also decreasing, enabling wider reach of sensor nodes. There are also many advancements in low power radio technologies which can be used to design more efficient systems.

Less maintenance is required for building wireless systems. Wireless networks also offer better scalability compared to wired networks, and deploying a new node in a wireless network is easier. Sensor networks need to balance performance versus the lifetime of the sensor node. Wireless nodes can be configured dynamically to balance this tradeoff, as well as operate autonomously to permit local control of operation and power management. A number of wireless protocols can be considered for sensor networks namely Zigbee, Bluetooth, GSM, Wi-Fi, etc. The choice of wireless protocol depends upon the application needs for the sensor network.

**Low power capability**

Wireless sensor nodes require very little maintenance and must run for days and sometimes months using the same battery. Thus, low power design is critical for the design of real-world wireless sensor networks, and it is a primary requirement that sensor nodes process and transmit sensor data while consuming very little power. As sensors in a sensor node typically measure slow varying analog quantities, nodes need only be active for a short duration to transmit data before they go back to sleep. This means that sensor nodes have to have excellent standby current capabilities. Also, most of the data transmission happens from the sensor nodes to the base station.

Low power capabilities must be developed in the following methods:

- Network architecture and communication protocols must exploit this asymmetry of sensor communication from sensor node to base station.
- Design of a low power sensor is critical. Micro Electro Mechanical Systems (MEMS) based sensors with low power capabilities are also critical.
- Low Power RF transceivers: Sensor nodes may operate in an environment of densely distributed nodes from different sources. Sensor nodes may also need to transmit using very low power in noisy environments.
**Aggregation of data from sensor nodes**

The data from a sensor network must be aggregated and processed in a centralized location. Data handling in a sensor network can be split into data dissemination and data gathering. Data dissemination is the process by which information is routed in the sensor network. This information could be data acquired from the sensor or requests for data from other sensors.

A number of algorithms are available for disseminating data across a sensor network. Data gathering algorithms maximize the number of communications that happen with a sensor node before the node dies. The trade off in this case is between delay and power consumption. In case of a direct transmission, every node sends collected data directly to a centralized network as in the case of nodes with GSM capabilities.

Nodes of a wireless sensor network would have an operating system ported onto it. This enables easy expansion of adding more wireless sensors and can enables modular development. The operating systems for sensor networks resemble embedded operating systems since they are developed keeping an application in mind and are not generic. Also, since the system is built with low power and low cost capabilities, most general purpose operating systems must be eliminated. Given that most sensor networks do not require real-time capabilities, a smaller operating system such as TinyOS that has been specifically designed for sensor nodes may be used.

Figure 3 shows a typical implementation of a sensor network using a GSM (Global system for mobile communication) modem. Here all of the sensors communicate their data to a centralized server. Also the server has control over individual sensor nodes; however, individual sensor nodes cannot communicate between themselves. The server has to be involved for any communication between any two sensor nodes.

![Figure3. Typical implementation of a Sensor Network](image)

**GSM modem**

GSM (Global System for Mobile communication) is one of the standards for mobile telephony in the world. Although initially used only for voice communication, it has been adapted to include data capabilities by means of GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution). A GSM modem is a type of modem which accepts a SIM (Subscriber Index Module) and operates like a mobile phone. With the boom in telecommunication equipment, the costs of GSM modems are dropping rapidly. Also, due to advancements in low power design capabilities of mobile phones, the current consumption of GSM modems is much less than it traditionally has been.

GSM modems can be used in low power mode or can also be turned off when they are not in use. The cost of transmitting data by GSM networks is also falling rapidly. A GSM modem can be easily interfaced to microcontrollers using standard communication protocols. Mobile phones are increasingly handling data along with voice. Most GSM modems have a TCP/IP stack implemented on them and can be used to transmit data over secure channels. This also reduces the complexity of developing applications and enables the use of simple microcontrollers to interface to the GSM modem.
A GSM modem can connect to any IP (Internet Protocol) address and transmit data. Multiple modems can send data to a single IP address, and all the data can be collected and processed from a single location anywhere in the world. Users can dynamically configure each and every modem remotely based on data sent across from the network. In certain networks, a single node would have GSM capability. Other nodes would send their data to this particular node to be transmitted to the centralized server. This could reduce the cost of the overall system but would not be possible if nodes are not clustered together. GSM modems also have the ability to provide instant alerts using SMS (short messaging service) or by transmitting data to a different, high-priority IP address based on certain conditions. These features can be used for fault tolerance and redundancy checks.

Let us consider an example of a GSM modem (SIM300) where communication happens over a serial port with the microcontroller. The modem has a standard set of commands called AT commands. These commands control the operation of the modem from the microcontroller. The microcontroller sends these commands over a UART (Universal Asynchronous Receive Transmit) interface at a specified baud rate. The data sent through the serial port can be transmitted to a centralized server by configuring the modem using a specific set of commands. Thus, interfacing with the GSM modem simplifies data acquisition and processing in sensor networks.

**Complete System Implementation**

A sensor node consists of an analog signal chain and also requires a host of digital peripheral interfaces. Also each sensor node may be interfaced to different kinds of sensors, requiring flexibility in its interfaces and I/Os. Programmability of individual nodes plays a critical role in a successful implementation of a sensor network. Mixed-signal programmable microcontrollers like PSoC from Cypress provide analog and digital subsystems which can be configured to provide the functionality required by individual nodes. This eliminates the need for specialized hardware for each different kind of sensor. Such System-on-Chip-based (SoC) microcontrollers also have the capability to handle all tasks required for the sensor node in a single chip, including ADC, DAC, PGA’s, comparators, op-amps, digital filtering capabilities, DMA, and LCD controllers, among others. Design of the system using SoCs allows frequent and fast changes in design to assist customization of sensors nodes. PSoC with its low power capabilities at sleep mode is very suitable for these applications. Figure 4 shows how most of a sensor node can be implemented using an SoC to reduce BOM cost and provide low power operation. Figure 5 shows the implementation of a typical sensor node using programmable mixed-signal resources.

![Figure 4. Simplified implementation of a Sensor Node using PSoC](image-url)
Figure 5. An Implementation of Sensor Node using PSoC

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