

Wireless Integrated Network Sensor for Border Security

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ABSTRACT

Wireless Integrated Network Sensors (WINS) now provide a new monitoring and control capability for monitoring the borders of the country. WINS combine sensing, signal processing, decision capability, and wireless networking capability in a compact, low power system. Using this concept we can easily identify a stranger or some terrorists entering the border. The border area is divided into number of nodes. Each node is in contact with each other and with the main node. The noise produced by the foot-steps of the stranger is collected using the sensor. This sensed signal is then converted into power spectral density and then compared with reference value of our convenience. Accordingly the compared value is processed using a microprocessor, which sends appropriate signals to the main node. Thus the stranger is identified at the main node. A series of interface, signal processing, and communication systems have been implemented in micro power CMOS circuits. A micro power spectrum analyzer has been developed to enable low power operation of the entire WINS system. But it is very cheaper when compared to other security systems such as RADAR under use. It produces a less amount of delay. Hence it is reasonably faster.

Keywords: CMOS, Micro sensors / MEMS, WINS

Introduction

A sensor is a device that produces a measurable response to a change in a physical condition, such as temperature or magnetic field. Although sensors have been around for a long time, two recent technological revolutions have greatly enhanced their importance and their range of application. The first was the connection of sensors to computer systems and the second was the emergence of MEMS sensors with their small size, small cost, and high reliability [1]. The evolution of microelectronics and communication technologies facilitates the manufacturing of miniature sensors comprising a small transmitter/receiver, a processor, memory components and a low-power battery [2], [3].

Wireless integrated network sensors (WINS) provide distributed network and Internet access to sensors is shown in Fig. 1. WINS combine sensor technology, signal processing, computation,

and wireless networking capability in integrated systems. These systems will have many applications, including security, medicine, factory automation, environmental monitoring, and condition-based maintenance. The opportunities for WINS depend on the development of scalable, low cost, sensor network architecture. This requires that sensor information be conveyed to the user at low bit rate with low power transceivers. Continuous sensor signal processing must be provided to enable constant monitoring of events in an environment. Recent advances in integrated circuit technology have enabled construction of far more capable sensors, radios, and processors at low cost, allowing mass production of sophisticated systems that link the physical world to networks [4].

WINS demonstrations have shown that defence systems will be fundamentally changed by low cost devices which are deeply and widely distributed in environments and integrated into assets for continuous, global monitoring and control for battlefield surveillance, security, environmental status, and condition based maintenance. There is now a confirmed set of WINS applications within the Department of Defence for battlefield surveillance and condition based maintenance on land, sea, and air vehicles. In addition, through the development at Sensoria (San Diego, California) [5], WINS networks are now Internet accessible, enabling global, remote, reconfigurable monitoring, control, and security [6].



Figure 1: Distributed Sensor at Border

Wins System Architecture

The WINS network must support large numbers of sensors in a local area with short range and low average bit rate communication (less than 1kbps). The network design must consider the requirement to service dense sensor distributions with an emphasis on recovering environment information. The WINS architecture, therefore, exploits the small separation between WINS

nodes to provide Multihop communication. This yields large power and scalability advantages for WINS networks. Therefore, Multihop Communication provides an immediate advance in capability for the WINS narrow Bandwidth devices. However, WINS Multihop Communication networks permit large power reduction and the implementation of dense node distribution. The multihop communication has been shown in the Fig. 3. The Fig.2. represents the general structure of the wireless integrated network sensors (WINS) arrangement.

Multihop communication yields large power and scalability advantages for WINS networks. First, RF communication path loss has been a primary limitation for wireless networking, with received power, P_{REC} , decaying as transmission range, R , as $P_{REC} \propto R^{-\alpha}$ (where α varies from 3 – 5 in typical indoor and outdoor environments). However, in a dense WINS network, Multihop architectures may permit N communication link hops between $N+1$ nodes. In the limit where communication system power dissipation (receiver and transceiver power) exceeds that of other systems within the WINS node, the introduction of N co-linear equal range hops between any node pair reduces power by a factor of $N^{\alpha-1}$ in comparison to a single hop system. Multihop communication, therefore, provides an immediate advance in capability for the WINS narrow bandwidth devices. Clearly, multihop communication raises system complexity. However, WINS multihop communication networks permit large power reduction and the implementation of dense node distribution.

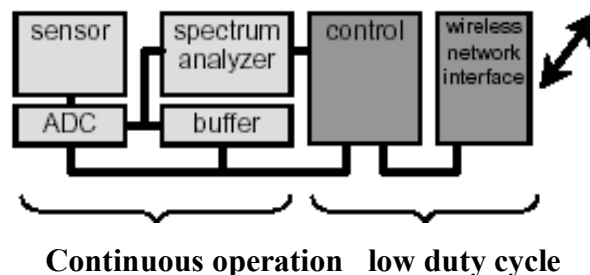


Figure 2: The wireless integrated network sensor

(WINS) architecture includes sensor, data converter, signal processing, and control functions. Micropower RF communication provides bidirectional network access for low bit rate, short range communication. The micropower components operate continuously for event recognition, while the network interface operates at low duty cycle.

Wins Node Architecture

WINS development was initiated in 1993, at UCLA. The first generation of field-ready WINS devices and software, were first fielded in 1996. The Low Power Wireless Integrated

Microsensors (LWIM-I) demonstrated the feasibility of multihop, self-assembled, wireless networks. This first network also demonstrated the feasibility of algorithms for operation of wireless sensor nodes and networks at micropower level. In a joint development program with the Rockwell Science Center, a modular development platform was devised to enable evaluation of more sophisticated networking and signal processing algorithms, and to deal with many types of sensors [7]. In 1998, the same team built a second generation sensor node, The Wireless Integrated Network Sensors (WINS).

The WINS node architecture is shown in Fig.3. Is developed to enable continuous sensing, event detection, and event identification. Since the event detection process must occur continuously, the sensor, data converter, data buffer, and spectrum analyzer must all operate at micro power levels. In the event that an event is detected, the spectrum analyzer output may trigger the microcontroller. The microcontroller may then issue commands for additional signal processing operations for identification of the event signal. Protocols for node operation then determine whether a remote user or neighbouring WINS node should be alerted. The WINS node then supplies an attribute of the identified event.

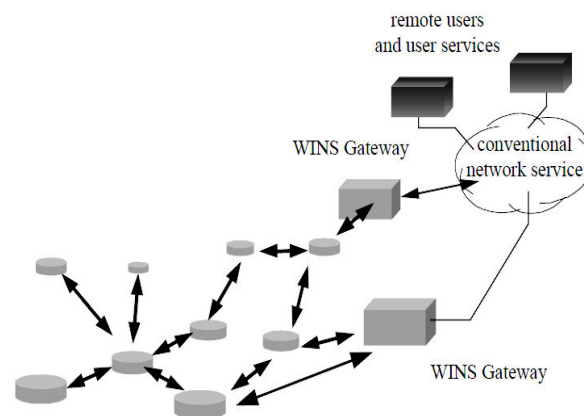


Figure 3: WINS Node Architecture

Primary LWIM applications require sensor nodes powered by compact battery cells. Total average system supply currents must be less than $30\mu\text{A}$. Low power, reliable and efficient network operation is obtained with intelligent sensor nodes that include sensor signal processing, control, and a wireless network interface. The signal processor described here can supply a hierarchy of information to the user ranging from single-bit event detection, to power spectral density (PSD) values, to buffered, real time data. This programmable system matches its response to the power and information requirements. Distributed network sensor devices must

continuously monitor multiple sensor systems, process sensor signals, and adapt to changing environments and user requirements, while completing decisions on measured signals. Clearly, for low power operation, network protocols must minimize the operation duty cycle of the high power RF communication system. Unique requirements for the WINS node appear for sensors and micropower sensor interfaces. For the particular applications of military security, the WINS sensor systems must operate at low power, sampling at low frequency and with environmental background limited sensitivity. Many of the primary WINS applications require sensor nodes powered by compact battery cells. Total average system supply currents must be less than $30\mu\text{A}$. to provide long operating life from typical compact Li coin cells (2.5 cm diameter and 1 cm thickness). In addition, these compact cells may provide a peak current of no greater than about 1 mA (higher peak currents degrade the cell energy capacity through electrode damage.) Both average and peak current requirements present unique challenges for circuit design.

A. Wins Microsensors

To maximize detection range, sensor sensitivity must be optimized. In addition, due to the fundamental limits of background noise, a maximum detection range exists for any sensor. Thus, it is critical to obtain the greatest sensitivity and to develop compact sensors that may be widely distributed. Clearly, microelectromechanical systems (MEMS) technology provides an ideal path for implementation of these highly distributed systems. WINS sensor integration relies on structures that are flip-chip bonded to a low temperature, co-fired ceramic substrate. This sensor-substrate “sensorstrate” is then a platform for support of interface, signal processing, and communication circuits. Examples of WINS infrared detector devices are shown in Fig. 4.

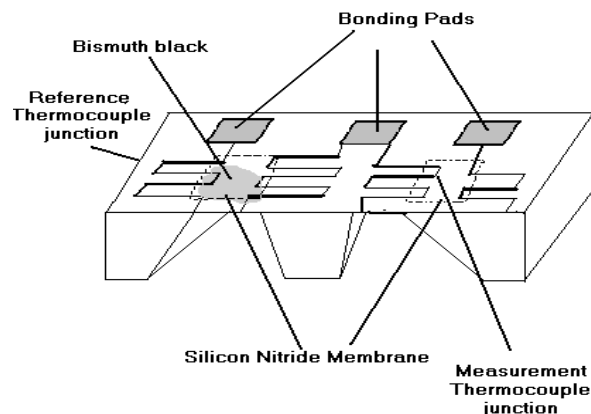


Figure 4: Thermal Infrared Detector

The detector shown is the thermal detector. It just captures the harmonic signals produced by the foot-steps of the stranger entering the border. These signals are then converted into their PSD values and are then compared with the reference values set by the user.

B. Wins Microsensor Interface Circuits

The WINS micro sensor systems must be monitored continuously by the CMOS micropower analog-to-digital converter (ADC). Power requirements constrain the ADC design to power levels of $30\mu\text{W}$ or less. Sensor sample rate for typical microsensor applications is less than 1 kHz. Also, it is important to note that the signal frequency is low. Specifically, the thermopile infrared sensor may be employed to detect temperature, presence, of motion at near dc signal frequencies. Therefore, the ADC must show high stability (low input-referred noise at low frequency). For the WINS ADC application, a first order Sigma-Delta ($\Sigma\text{-}\Delta$) converter is chosen over other architectures due to power constraints. The ($\Sigma\text{-}\Delta$) architecture is also compatible with the limitations of low cost digital CMOS technologies.

The analog components of the ADC operate in deep subthreshold to meet the goal of micropower operation [8]. This imposes severe bandwidth restrictions on the performance of the circuits within the loop. A high oversampling ratio of 1024 is thus chosen to overcome the problems associated with low performance circuits. The possible increased power consumption of digital components in the signal path including the low pass filter is minimized with the use of low power cell libraries and architecture. Implementation of low noise ADC systems in CMOS encounters severe “ $1/f$ ” input noise with input noise corner frequencies exceeding 100 kHz. The WINS ADC applications are addressed by a first-order converter architecture combined with input signal switching (or chopping). The chopper ADC heterodynes the input signal to an intermediate frequency (IF) before delivery to the ($\Sigma\text{-}\Delta$) loop. An IF frequency of $1/8$ of the ADC sampling frequency is chosen. The low thermopile sensor source impedance limits the amplitude of charge injection noise that would result from signal switching. The required demodulation of the IF signal to the desired baseband is accomplished on the digital code modulated signal, rather than on the analog signals. This both simplifies architecture and avoids additional injected switching noise. The architecture of the chopped ($\Sigma\text{-}\Delta$) ADC. Division of Computer Science, SOE 12 Wireless Integrated Network Sensor The first order ($\Sigma\text{-}\Delta$) ADC has been fabricated in the HPCMOS 0.8m process. Direct measurement shows that the converter achieve greater than 9 bit resolution for a 100 Hz band limited signal with a power consumption

of only $30\mu\text{W}$ on a single 3V rail. This chopper ADC has been demonstrated to have a frequency-independent SNR from 0.1 – 100Hz. This resolution is adequate for the infrared sensor motion detection and temperature measurement applications [9].

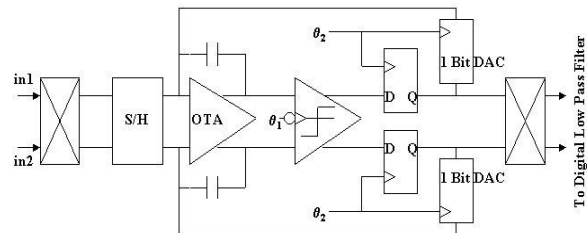


Figure 5: WINS (□-□) ADC a block diagram of the pulse code modulator

C. Wins Digital Signal Processing

If a stranger enters the border, his foot-steps will generate harmonic signals. It can be detected as a characteristic feature in a signal power spectrum. Thus, a spectrum analyzer must be implemented in the WINS digital signal processing system. The spectrum analyzer resolves the WINS 8-bit ADC input data into a low resolution power spectrum. Power spectral density (PSD) in each of 8 frequency “bins” is computed with adjustable band location and width. Bandwidth and position for each power spectrum bin is matched to the specific detection problem. The complete WINS system, containing controller and wireless network interface components, achieves low power operation by maintaining only the micropower components in continuous operation. The WINS spectrum analyzer system, shown in Fig. 6, contains a set of 8 parallel filters. Mean square power for each frequency bin is computed at the output of each filter. Each filter is assigned a coefficient set for PSD computation. Finally, PSD values are compared with background reference values (that may be either downloaded or learned). In the event that the measured PSD spectrum values exceed that of the background reference values, the operation of a microcontroller is triggered. Thus, only if an event appears does the microcontroller operate. The microcontroller may support additional, more complex algorithms that provide capability (at higher power) for event identification.

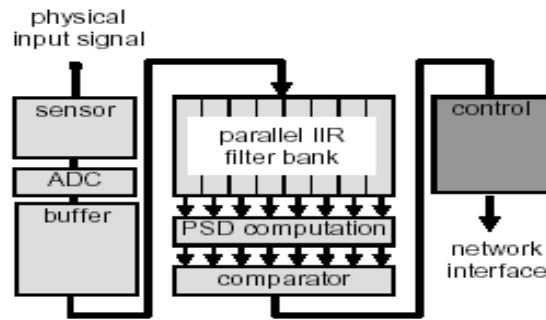


Figure 6: WINS micro power spectrum analyser architecture.

The WINS spectrum analyser architecture [10] includes a data buffer, shown in Fig. 6. Buffered data is stored during continuous computation of the PSD spectrum. If an event is detected, the input data time series, including that acquired prior to the event, are available to the microcontroller. The micro controller sends a HIGH signal, if the difference is high. It sends a LOW signal, if the difference is low. For a reference value of 25db, the comparison of the DFT signals is shown in the Fig. 7. Low power operation of the spectrum analyzer is achieved through selection of an architecture that provides the required performance and function while requiring only limited word length.

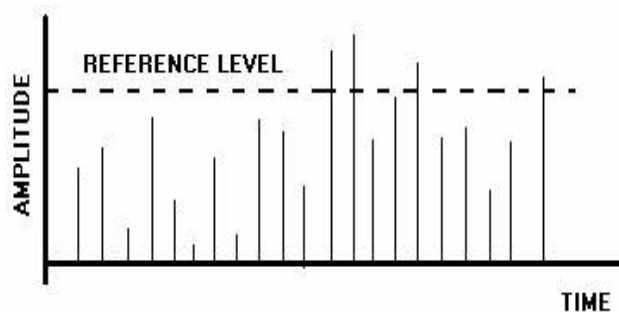


Figure 7: Comparator plot

D. Energy Consumption in Integrated Circuit

Complementary metal–oxide–semiconductor (CMOS), Is a technology for constructing integrated circuits. Two important characteristics of CMOS devices are high noise immunity and low static power consumption. Significant power is only drawn while the transistors in the CMOS device are switching between on and off states. Consequently, CMOS devices do not produce as much waste heat as other forms of logic. CMOS also allows a high density of logic functions on a chip. It was primarily this reason why CMOS won the race in the eighties and

became the most used technology to be implemented in VLSI chips. Integrated MEMS sensors with CMOS technology, RF circuits and small-sized microchip of fully integrated wireless smart microsensors will be realized mostly in the near future [11].

E. Routing Between Nodes

The sensed signals are routed to the major node. This routing is done based on the shortest distance. That is the distance between the nodes is not considered, but the traffic between the nodes is considered. This has been depicted in the Fig. 8. In the figure, the distances between the nodes and the traffic between the nodes have been clearly shown. For example, if we want to route the signal from the node 2 to node 4, the shortest distance route will be from node 2 via node 3 to node 4. But the traffic through this path is higher than the path node 2 to node 4. Whereas this path is longer in distance.

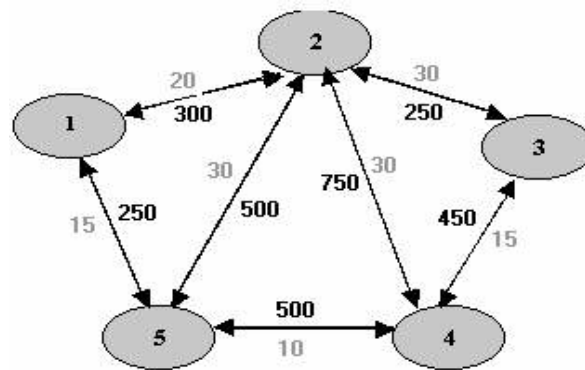


Figure 8: Nodal distance and Traffic

F. Embedded Operating Systems for Sensors Platforms

In order to manage the hardware of a sensor, an operative system is needed. It is responsible to make the sensor to carry out its operations and tasks. A major difference between sensor networks and more traditional computing platforms, it is the extreme emphasis in sensor networks on power management. A large number of applications require battery-powered operation for extended periods of time. In order to manage power efficiently, each subsystem of the platform is powered individually.

Several operative systems have been developed for the sensors such as Bertha [12], MagnetOS [13], LiteOS [14], TinyOS [15], and so on. Their main features are:

- 1) *Bertha (pushpin computing platform):* It is a software platform designed to deploy a distributed WSN with a lot of identical nodes.

- 2) *MagnetOS*: It is a distributed operative system for sensor or ad-hoc networks. Its objective is to run network applications of low consumption devices. It is very adaptive and easy to implement.
- 3) *Lite OS*: It is a multi-threaded operating system that provides Unix-like abstractions for wireless sensor networks. It offers a hierarchical file system and a wireless shell interface for user interaction.

TinyOS: The most popular single-node operating system [16] it is used for Tmote Sky. It is a reduced multi tasks core useful for small devices, like the sensors. It is an “event-driven” operative system, that is, when an event happened, this calls to the corresponding functions. It has been developed for WSNs with limited resources. The programming of sensors is quite complicated because they have a limited calculus capacity and very few resources. Several programming languages have been developed to program the sensors. Some of them are nesC [17], Protothreads [18], Giotto [19], and so on. The libraries and applications of TinyOS are written in nesC, a version of C designed to program embedded systems. In nesC, the programs are composed by linked components.

Conclusion

Wireless integrated network sensor (WINS) technology will provide a bridge between the physical world and the exponentially growing information infrastructure. The network is self-monitoring and secure. Now it is possible to secure the border with an invisible wall of thousands or even millions of tiny interconnected sensors. Recently complete prototype WINS networks have been demonstrated in defence.

A series of interface, signal processing, and communication systems have been implemented in micropower CMOS circuits. A micropower spectrum analyzer has been developed to enable low power operation of the entire WINS system. Thus WINS require a Microwatt of power. But it is very cheaper when compared to other security systems, it is even used for short distance communication less than 1 Km. it produces a less amount of delay. Hence it is reasonably faster. On a global scale, WINS also permit monitoring of land, water, and air resources for environmental monitoring. On a national scale, transportation systems, and borders will be monitored for efficiency, safety, and security.

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