UWB Ad-Hoc Wireless Sensor Network for Structural Health Monitoring and Facility Management of Warehouses

Vineeta Philip[#1], Pratikkumar Bharti[#2], Ketankumar Dorik[#2], Aishwarya Venkatesh[#2],
Munazza Farha Arshi[#2]

[#1] *Assistant Professor, Department of Electronics Engineering, SPPU*
[#2] *Student, Department of Electronics Engineering, SPPU*
Department of Electronics Engineering, AISSMS IOIT, Pune-411001 Savitribai Phule Pune University, Pune, Maharashtra, India

Abstract— *In this paper we highlight optimization framework for UWB ad hoc networks in order to promote four performance goals: maximizing throughput; promoting fair access; minimizing connection setup latency; and minimizing control overhead. Each node maintains a local state table that includes perceived interference, received radio power, communication resource allocation for different traffic classes, and reliability. Nodes use this state information to adapt the transmission rate and power of their active links in order to maintain link quality guarantees. Nodes also adapt the neighbour costs and the period of their state declaration (hello) messages according to changes in local and neighbourhood state. Also we base our results on OFDM transceiver simulation as physical layer in ASIC radio. Within the optimization framework, we present UWB-MAC, an adaptive Medium Access Control (MAC) protocol for UWB building on TinyOS RTOS in which nodes periodically declare their current state, so that neighbours can assign power and rate values for new links locally in order to optimize global network performance.*

Keywords— *OFDM transceiver design, UWB-MAC design, Ad- Hoc Wireless sensor networks, Structural Health Monitoring.*

I. INTRODUCTION

Wireless sensor networks have evolved from the idea that small wireless sensors can be used to collect information from the physical environment in a large number of situations ranging from wild fire tracking and animal observation to agriculture management and industrial monitoring. Each sensor wirelessly transmits information toward a base station. Sensors help each other to relay the information to the base station. Wireless sensor networks are composed of small nodes, equipped with a wireless communication device, that autonomously configure themselves into networks through which sensor readings can be transported. Furthermore, wireless sensor networks are primarily intended to be operated over a wireless radio communications device.[2]

Structural health monitoring (SHM) defines an abstract condition for a physical structure such as a bridge, crane, tower, or other physical object or even heavy machinery. Measurement data are used to monitor physical quantities and computer models are used to analyze the data and classify the current state of the structure and trigger alerts if necessary. SHM typically becomes a part of the structure for its entire lifetime, and the structure's condition will be inferred from its physical measurements. Due to the lifetime requirements and physical size of the objects, wiring of the sensors recording physical quantities is not a preferred solution or even possible, especially for existing structures not equipped with wiring. Enabling SHM on such structures would be a major investment and effort. In most cases, smart objects are interconnected via low-power wireless links, a solution that avoids costly and error prone wiring within the structure.

We have decided to focus on only one particular infrastructure which is Warehouse. Warehouses in India are pieces of relic and most of them require retrofitting to be deemed worthy of use. So to model our Wireless Sensor Network (WSN) for Structural Health Monitoring (SHM) we have decided upon Warehouse to be our main focus in deployment of Sentient Network. Warehouses in India do not provide modern amenities like cold storage. Also warehouses are most susceptible to fire hazards which is one of the main reasons of losses both material and men. Also energy consumption in warehouses is high so energy monitoring and providing protection against electrical anomalies is of utmost importance.

Ultra wideband radio (UWB) is a spread-spectrum technique that is based on the modulation of short nanosecond pulses using OFDM. The short duration of pulses results in the thin spreading of the signal over a large spectral bandwidth. Consequently, UWB communication is robust to frequency selective and multipath fading and supports high data rates. In recent years, UWB has received increasing recognition for its applicability to short to medium range communication networks because of desirable features such as high data rates, low power consumption, precise ranging capabilities, resistance to multi-path fading, and penetration of dense objects. UWB is currently a candidate technology for short range high transfer rate applications such as the simultaneous transfer of multiple video streams in a Wireless Personal Area Network (WPAN)[3]. It is also being considered for medium range sensor networks with lower transfer rates.[6][5]

UWB also has an established positioning capability because it has been used for ground-penetrating radar applications by the military for more than half a century. UWB's positioning capability makes it suitable for sensor networks in the presence of physical obstacles, such as walls. Similarly, UWB is suitable for wireless communication in sensor networks that are embedded in the ground, for instance monitoring the soil in agricultural fields, or in man-made physical structures, such as bridges. Thus making it good choice in Structural Health Monitoring.

II. TECHNICAL CHALLENGES

One of the main challenges with SHM is that the structure health is not determined by a single measured quantity. There is no single sensor that tells directly if, for example, a bridge is going to collapse. The only viable methodology consists of periodically measuring a series of physical quantities and then using various data analysis and data mining techniques to analyze the data and find irregularities or changes that could be a sign of an emerging problem.[1]

The structure's condition must be described by the physical quantities measured from the structure. Typical physical quantities include accelerations, strains, pressure, temperature, wind speed, flow, position, orientation, chemical quantities, and wave propagation quantities. Timely availability of the measurements has a large effect on the delay of detection, therefore near real-time measurements are used. This also sets requirements on the transmission bandwidths of the network. While monitoring the structure, only the output measurements are available, without knowing the state (or condition) of the structure or the input that caused the damage. In the subsequent analysis phase, it is assumed that these measurements are representative of the normal condition of the structure.

III. OBJECTIVES

1. To monitor and control various natural and infrastructure systems that affect the urban environment
2. To define an abstract condition to model the structure i.e. the modeling of loads and forces acting on warehouse building to monitor the health and providing aggregated data collated on cloud.
3. Energy consumption monitoring and cold storage automation.
4. To use measurement data to monitor physical quantities and using computer models to analyze the data and classify the current state of the structure and trigger alerts if necessary.
5. To design Co-simulation model of OFDM Transceiver using Simulink-Verilog environment.
6. The introduction of adaptive periods for hello messages in an UWB network so that control message overhead is minimized
7. A comparative assessment with the reactive approach regarding control overhead, link setup latency, network throughput and adaptability
8. The development of mechanisms that promote fair access among nodes in an UWB network.

IV. SYSTEM DESCRIPTION

A central problem in UWB networks is the joint optimization of transmission power and transmission rates for active links. The joint rate and power assignment problem in UWB involves complex tradeoffs between fair rate assignment, network efficiency, and QoS, which cut across traditional layer boundaries. A high power link may achieve high transmission rates, but it also causes high interference which limits the rate available to neighbouring links. On the other hand, a low power link promotes fair access to the wireless medium but yields lower transmission rates. Thus, nodes must collaboratively determine the optimal rate and power values for new links in the network. *[8]*

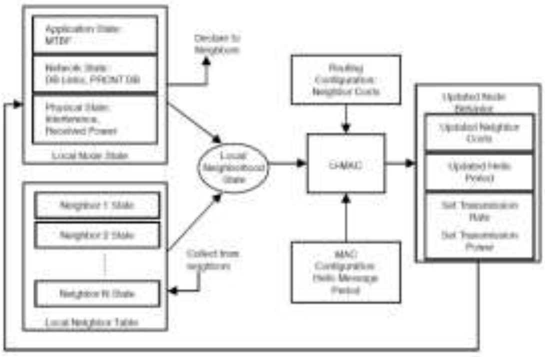

Fig. 1 Customized framework for UWB ad hoc network.

A. UWB Traffic Classes

We consider two traffic classes for UWB networks, in accordance with the specifications of the European Whyless Project to address the requirements of different application types:

(1) Reserved Bandwidth (RB);
(2) Dynamic Bandwidth (DB).

The RB traffic class is geared towards continuous, realtime or multimedia traffic, since it requires quality guarantees prior to establishing a link. The continuous nature of traffic that exploits the RB traffic class requires that the link rate remain constant throughout the lifetime of the link.

DB traffic does not offer any rate guarantees and is thus suitable for best effort data, such as internet traffic. As the name implies, the rate of a link is dynamic and elastic, and depends on the number of other active DB links and on interference levels in the network. For instance, if the traffic load in a network is low, then individual DB links may use higher rates.

B. U-Mac Protocol

U-MAC addresses the joint rate and power assignment problem for UWB links for both RB and DB traffic. In general, each node in the network is the receiver for a certain number of communication links. Based on the quality requirements of its currently active links, the node can tolerate a finite amount of additional interference, referred to as maximum sustainable interference (MSI) .The MSI at each node must be efficiently and fairly divided up between RB and DB traffic and among links of each traffic class. Initially, each node's resources are split evenly between RB and DB traffic. As a node starts receiving link requests, the MSI portion allocated to each traffic type can adapt to the relative number of links in each traffic class. In general, at any point in time, each node allocates a portion λ of its MSI to DB traffic, and the remaining portion $(1 - \lambda)$ to RB traffic, where λ is less than one.

During the lifetime of the link, new communication links may cause the noise to increase, which subsequently causes quality degradation of the link. Avoiding quality degradation can be achieved in several ways:

- Increasing transmission power
- Decreasing transmission rate
- Providing a quality margin above MQR

The minimum quality requirement initially so that when new links are set up, the link can tolerate additional interference.Although increasing the transmission power maintains link quality and transmission rate, it degrades the quality of neighboring links which may require additional power or rate adjustments in the network. Furthermore, the FCC has imposed tight limits on UWB emissions so increasing transmission power to maintain quality is impractical. Alternatively, the link transmission rates can be lowered to maintain quality in response to increasing interference. This option does not require reconfiguration of neighbouring links, but it leads to inefficient use of the medium and may cause quality violations if the link carries RB traffic. Thus, U-MAC allows reducing link transmission rates only for DB traffic. Finally, providing quality margins avoids both rate and power adjustments of any active links, which suits RB links. The drawback of quality margins is that they also lead to less than optimal medium utilization.

U-MAC adopts Signal to Noise Ratio (SNR) as the main link signal quality metric. The SNR of a new link must have some margin above the minimum acceptable SNR for the link. In U-MAC, the parameter μ determines the size of the SNR quality margin of links. The value of μ could be static or adaptive to the spatial distribution of nodes, the traffic load, and the lifetime of the link.

IV. SYSTEM DESIGN

The Network system has been broken into five subsystems during the development process as shown in Figure 2. The controller subsystem handles just about everything on the microcontroller, including the software state machine and the network topology. The sensor subsystem includes both the PIR motion sensor, debouncer to reduce false alarms, an alarm inhibitor, and a way for the alarm to wake up the controller. The power supply subsystem functions as the power supply of the system. The RF subsystem handles the PHY and MAC layer wireless data transmission between the various network nodes; it includes the RF transmitter and SPI interface. Finally, the UI subsystem handles both desktop application for the user, the serial communication between the network node and desktop application, and the serial communication protocol shared by the network node and desktop application. Scope of each subsystem has a clear functional, versus hardware or software, distinction. Each subsystem is to handle certain aspects of the overall system requirements independently by itself. For example, the overall desire to reduce power consumption is addressed within the design of each individual subsystem instead of a separate subsystem. In other words, each subsystem is responsible for adhering to the functional and objective requirements of its components.

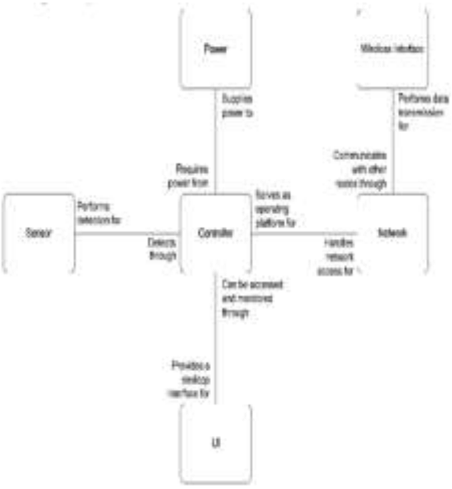

Fig.2 System Block Diagram.

A. Hardware

1. PIC18F4550 SPECIAL MICROCONTROLLER FEATURES:
    a. C Compiler Optimized Architecture with optional Extended Instruction Set.
    b. 100,000 Erase/Write Cycle Enhanced Flash Program Memory typical.
    c. 1,000,000 Erase/Write Cycle Data EEPROM Memory typical
    d. Flash/Data EEPROM Retention: > 40 years
    e. Self-Programmable under Software Control
    f. Priority Levels for Interrupts • 8 x 8 Single-Cycle Hardware Multiplier
    g. Extended Watchdog Timer (WDT):
    h. Programmable period from 41 ms to 131s
    i. Programmable Code Protection
    j. Single-Supply 5V In-Circuit Serial
    k. Programming™ (ICSP™) via two pins
    l. In-Circuit Debug (ICD) via two pins
    m. Optional dedicated ICD/ICSP port (44-pin devices only)
    n. Wide Operating Voltage Range (2.0V to 5.5V)

2. ***BATTERY***

3. ***SENSORS For SHM***

- Strain gauges, Gyroscopes, Pressure sensors(capsules,bellows), accelerometers
- For Cold Storage Facility Management Temperature sensors (thermocouple, or smart sensor like LM35 or LM75)
- For Tackling Fire Hazards
  Heat sensors, Temperature sensors

B. Software Algorithm

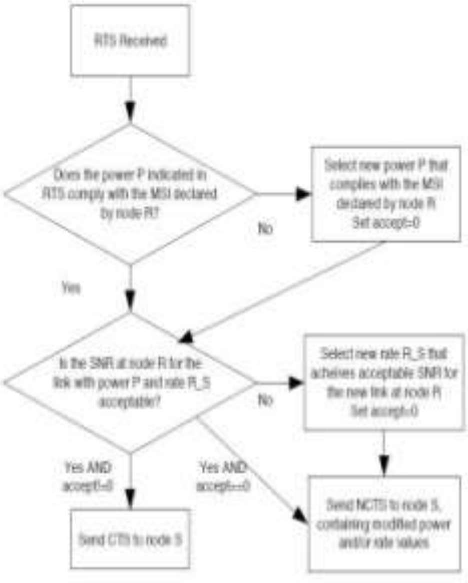

Fig.3 Receiver Behaviour.

The software of the overall system resides on the microcontroller and PC. While the PC software design is fairly straight forward in that it only needs to interface with the microcontroller through a serial port, sending it data, and parsing the data it outputs, the microcontroller embedded software design is more complicated.

The controller subsystem makes up the bulk of the code by designing the structure, state machine, initialization, and standard operation of the firmware. While the Network subsystem is responsible for initialization of the RF transceiver through the microcontroller and implementing a complete PHY and MAC layered library for the main code to change states, access registers, and send/receive data, it is the controller subsystem that performs the high level network topology control. As for the sensor and UI subsystems, while they are responsible for the software implementation of sensor detection and UI interface respectively, there is a less clear distinct between them and the main controller software subsystem. Since the sensor software requires timing and sleep functionalities, it relies on the controller software to handle those tasks. The UI software needs to not only implement the UART interface but also establish the communication protocol shared between the microcontroller and PC; this requires debug printouts to be established everywhere on software and ensure the microcontroller code checks for access requests from the PC.

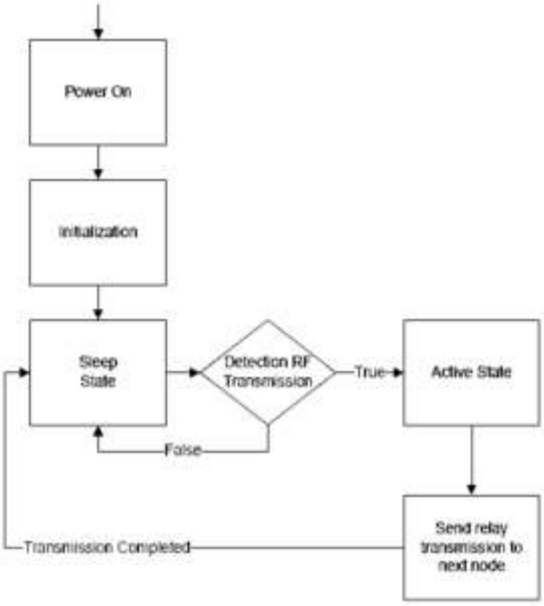

Fig.4 Sensor Node Behaviour Software Flow.

The sensor node requires shifting between a sleep and active state to conserve power. It uses the RF transceiver to make the transition after it detects a valid RF transmission. After downloading the received data and parsing it, the relay node will then relay it down to the way topology supports Multihopping. The complete software is built onto TinyOS by UCBerkeley which is made specially for WSN.

V. TEST AND RESULT

The system was tested by using various sensors like temperature sensor, pressure sensor and the data from the sensors was checked. It was found that the system worked successfully as per the design. When the sensors sense abnormalities in the surrounding, they send the data of the structure health through the various nodes in the system. After receiving the digital data on the receiver side , the data is checked and further action is taken . There were no faults experienced during the working of the system, All the actions took place automatically without the interference of any man force.

VI. CONCLUSION

As seen in the recent times, natural calamities have struck and wrecked havoc upon people. People have lost their lives, primarily not due to the calamity itself but because of the failure and collapsing of structures. The characteristic of one such calamity that is, an earthquake is that structures do not collapse immediately, rather there is a time period before the failure. Our system helps in monitoring the structures and prevent any further loss of mankind.

ACKNOWLEDGEMENT

We would like to thank Prof.Vineeta Philip for being the most helpful guide we could ask for. Her insights have had valuable impact on our methodologies. Pratikkumar Bharti thanks Prof. Nilima Warade for providing valuable inputs in OFDM implementation especially for providing FFT implementation techniques and feasibility. Ketankumar Dorik thanks Prof. Mausami Vanjale for her critique of software architecture and design methodology. Munazza Farha Arshi thanks Prof. Shobha Nikam for providing insights in algorithm development for transceiver implementation and also system modelling. Aishwarya Venkatesh thanks Prof. Kunal Ranveer for providing exceptional help much needed to understand RTOS concepts. We are highly indebted to our department for its support and encouragement.

REFERENCES

[1] Basheer, M. R., Rao, V., and Derriso, M., 2003, "Self-organizing Wireless Sensor Networks for Structural Health Monitoring," in Proceedings of the 4th International Workshop on Structural Health Monitoring, Stanford, CA, September 15–17, 1193–1206.

[2] Mitchell, K., Rao, V. S., and Pottinger, H. J., 2002, "Lessons Learned About Wireless Technologies for Data Acquisition," in Smart Structures and Materials 2002: Smart Electronics, MEMS, and Nanotechnology, San Diego, CA, March 18–21, Proceedings of the SPIE, Vol. 4700, 331–341.

[3] Institute of Electrical and Electronics Engineers (IEEE), 2003, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Network (LRWPANs), IEEE, New York, NY.

[4] Federal Communications Commission: "Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems", First Report and Order, ET Docket 98-153, 04-2002.

[5] Multiband OFDM Physical Layer Proposal for IEEE 802.15.3a,September 2004, http://www.multibandofdm.org

[6] Y. J.Y. Le Boudec, R. Merz, B. Radunovic and J. Widmer, "A MAC protocol for UWB Very Low Power Mobile Ad-hoc Networks based on Dynamic Channel Coding with InterferenceMitigation", EPFL Technical Report ID: IC/2004/02, 01-26-2004.

[7] R. Jurdak. "Modeling and Optimization of Ad Hoc and Sensor Networks," Bren School of Information and Computer Science, University of California Irvine. Ph.D. Dissertation. September, 2005

[8] R. Jurdak, P. Baldi, and C. V. Lopes."U-MAC: A Proactive and Adaptive UWB Medium Access Control Protocol". Wiley Wireless Communications and Mobile Computing Journal, 5(5):551-566, 2005