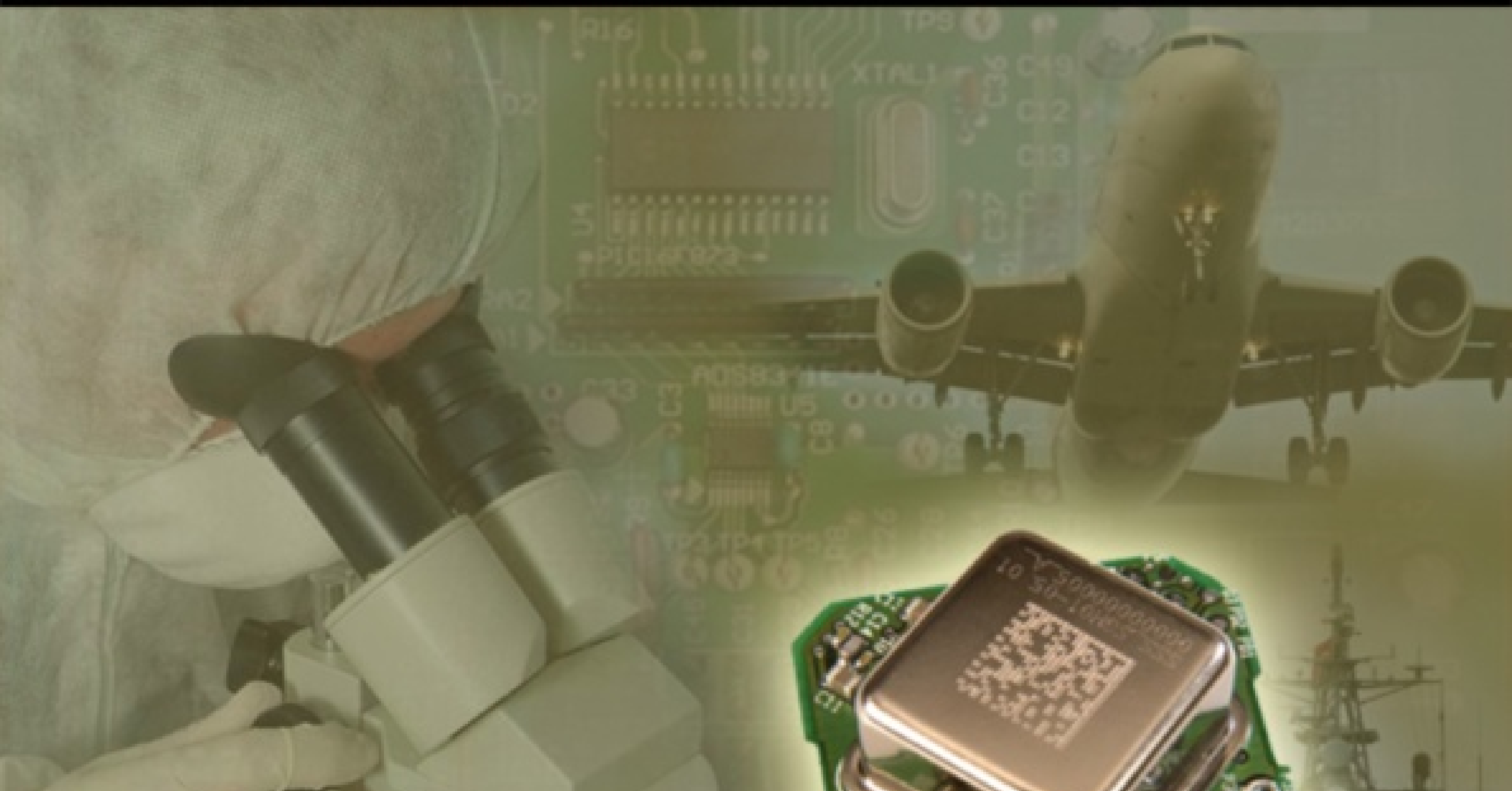
ISSN 1726-5749

SENSORS & TRANSDUCERS

4/08
vol. 90
Special



Modern Sensing Technologies

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and CD-ROM.

Sensors & Transducers Journal

Contents

Volume 90
Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Special Issue on Modern Sensing Technologies

Editorial

Modern Sensing Technologies
Subhas Chandra Mukhopadhyay and Gourab Sen Gupta.. I

Sensors for Medical/Biological Applications

Characteristics and Application of CMC Sensors in Robotic Medical and Autonomous Systems
X. Chen, S. Yang, H. Natuhara K. Kawabe, T. Takemitu and S. Motojima 1

SGFET as Charge Sensor: Application to Chemical and Biological Species Detection
T. Mohammed-Brahim, A.-C. Salaün, F. Le Bihan.. 11

Estimation of Low Concentration Magnetic Fluid Weight Density and Detection inside an Artificial Medium Using a Novel GMR Sensor
Chinthaka Gooneratne, Agnieszka Łekawa, Masayoshi Iwahara, Makiko Kakikawa and Sotoshi Yamada 27

Design of an Enhanced Electric Field Sensor Circuit in 0.18 μm CMOS for a Lab-on-a-Chip Bio-cell Detection Micro-Array
S. M. Rezaul Hasan and Siti Noorjannah Ibrahim.. 39

Wireless Sensors

Coexistence of Wireless Sensor Networks in Factory Automation Scenarios
Paolo Ferrari, Alessandra Flammini, Daniele Marioli, Emiliano Sisinni, Andrea Taroni.................... 48

Wireless Passive Strain Sensor Based on Surface Acoustic Wave Devices
T. Nomura, K. Kawasaki and A. Saitoh 61

Environmental Measurement OS for a Tiny CRF-STACK Used in Wireless Network
Vasanth Iyer, G. Rammurthy, M. B. Srinivas.. 72

Ubiquitous Healthcare Data Analysis And Monitoring Using Multiple Wireless Sensors for Elderly Person
Sachin Bhardwaj, Dae-Seok Lee, S.C. Mukhopadhyay and Wan-Young Chung 87

Capacitive Sensors

Resistive and Capacitive Based Sensing Technologies
Winncy Y. Du and Scott W. Yelich 100

A Versatile Prototyping System for Capacitive Sensing
Daniel Hrach, Hubert Zangl, Anton Fuchs and Thomas Bretterklieber 117

The Physical Basis of Dielectric Moisture Sensing
J. H. Christie and I. M. Woodhead 128

Sensors Signal Processing

Kalman Filter for Indirect Measurement of Electrolytic Bath State Variables: Tuning Design and Practical Aspects
Carlos A. Braga, Joâo V. da Fonseca Neto, Nilton F. Nagem, Jorge A. Farid and Fábio Nogueira da Silva 139

Signal Processing for the Impedance Measurement on an Electrochemical Generator
El-Hassane Aglzim, Amar Rouane, Mustapha Nadi and Djilali Kourtiche 150

Gas Sensors

Gas Sensing Performance of Pure and Modified BST Thick Film Resistor
G. H. Jain, V. B. Gaikwad, D. D. Kajale, R. M. Chaudhari, R. L. Patil, N. K. Pawar, M. K. Deore, S. D. Shinde and L. A. Patil 160

Zirconia Oxygen Sensor for the Process Application: State-of-the-Art
Pavel Shuk, Ed Bailey, Ulrich Guth 174

Image Sensors

Measurement of Digital Camera Image Noise for Imaging Applications
Kenji Irie, Alan E. McKinnon, Keith Unsworth, Ian M. Woodhead 185

Calibration-free Image Sensor Modelling Using Mechanistic Deconvolution
Shen Hin Lim, Tomonari Furukawa 195

Miscellaneous

Functional Link Neural Network-based Intelligent Sensors for Harsh Environments
Jagdish C. Patra, Goutam Chakraborty and Subhas Mukhopadhyay 209

MEMS Based Pressure Sensors – Linearity and Sensitivity Issues
Jaspreet Singh, K. Nagachenchaiah, M. M. Nayak 221

Slip Validation and Prediction for Mars Exploration Rovers
Jeng Yen 233

Actual Excitation-Based Rotor Position Sensing in Switched Reluctance Drives
Ibrahim Al-Bahadly 243

A Portable Nuclear Magnetic Resonance Sensor System
R. Dykstra, M. Adams, P. T. Callaghan, A. Coy, C. D. Eccles, M. W. Hunter, T. Southern, R. L. Ward 255

A Special Vibration Gyroscope
Wang Hong-wei, Chee Chen-jie, Teng Gong-qing, Jiang Shi-yu 267

An Improved CMOS Sensor Circuit Using Parasitic Bipolar Junction Transistors for Monitoring the Freshness of Perishables
S. M. Rezaul Hasan and Siti Noorjannah Ibrahim 276

Sensing Technique Using Laser-induced Breakdown Spectroscopy Integrated with Micro-droplet Ejection System
Satoshi Ikezawa, Muneaki Wakamatsu, Joanna Pawłat and Toshitsugu Ueda 284

A Forward Solution for RF Impedance Tomography in Wood
Ian Woodhead, Nobuo Sobue, Ian Platt, John Christie.. 294

A Micromachined Infrared Senor for an Infrared Focal Plane Array
Seong M. Cho, Woo Seok Yang, Ho Jun Ryu, Sang Hoon Cheon, Byoung-Gon Yu, Chang Auck Choi.. 302

Slip Prediction through Tactile Sensing
Somrak Petchartee and Gareth Monkman.. 310

Broadband and Improved Radiation Characteristics of Aperture-Coupled Stacked Microstrip Antenna for Mobile Communications
Sajal Kumar Palit 325

The Use of Bragg Gratings in the Core and Cladding of Optical Fibres for Accurate Strain Sensing
Ian G. Platt and Ian M. Woodhead 333

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

Sensors & Transducers Journal, Vol. 90, Special Issue, April 2008, pp. 72-86

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Environmental Measurement OS for a Tiny CRF-STACK Used in Wireless Network

Vasanth Iyer, G. Rammurthy, M. B. Srinivas
International Institute of Information Technology, Gachibowli, Hyderabad, (A.P.), India
Tel.: -500 032 91-40-2300 1967, fax: 91-40-2300 1413
E-mail: vasanth@research.iiit.ac.in, rammurthy, srinivas{@iiit.ac.in}, http://www.iiit.net

Received: 15 October 2007 /Accepted: 20 February 2008 /Published: 15 April 2008

Abstract: To respond to the new development needs of sensor networks and their unique deployment, there are many available processors and varying target footprints for deploying sensor networks. The most common needs are supporting many different types of wireless radios and an environmental measuring operating system which allows interfacing to 8, 16 bit target microcontrollers. The constraints of the sensor nodes (that form the network) however, are that they have limited processing power, limited wireless range, limited memory, low data transmission rates and low cost packaging. The design of the software stack being proposed in this paper is based on the previous work by the authors who focused on implementation of Control Radio Flooding (CRF) protocol to self organizing sensor networks. The proposed stack, which is fully power-aware, is referred to as CRF-STACK. It integrates the hierarchical space partitioning tree with a data transaction model that allows seamless exchanges between data collecting sensors and its parent nodes in the hierarchy and could be compatible with emerging IEEE standards. This heart of model is a scalable real-time OS which allows a programming interface to develop sensor application and underlying radio communication. Through routing simulations we demonstrate that the energy-aware reusability of resources in sensor networks has a $O(logN)$ complexity where N is the total number of nodes. In sensor network the processing power for a given operation is typically measured as a collaborative processing of a group of nodes which is always higher than the individual sensors capabilities, the residual energy remaining of the sensor network at the end of the simulation is a good measure of the collaborative factor (lesser the residual value the better the collaborative factor). We show by simulation the optimal values for reusability to attain max lifetime converges without sensor faults for N <= 20% for CRF and LEACH-E. Even though LEACH-S results peak at routing N=5% it has a complex lifetime with errors with a residual energy after faults at 27.9%. To accommodate the lifetime with faults in the case of LEACH we extend this static sensor network model with a fault-recognition algorithm making the real-time values measured from sensors more fault resistant and reliable throughout its maximum life-time. *Copyright © 2008 IFSA.*

Keywords: State machine stack, Sensor networks, Routing protocols, Fault recognition algorithms

1. Introduction

With the availability of low-cost sensor nodes there have been many standards developed to integrate and network these nodes to form a reliable network allowing many different types of hardware vendors to coexist. Most of these solutions however have aimed at industry-specific interoperability but not the size of the target footprint and the description of published standards usually run into hundreds of pages. In the proposed design we use a simple data transaction model which keeps the memory requirements low and configures the sensor network using CRF discovery protocol and routes the sensed data using an application specific polling rate.

The heart of the design is a small foot print OS which implements a caching based energy-aware router which attains a peak collaborative factor, the implementation divides the rest of the sensors into 1-hop and 2-hop data sensing devices. These ad-hoc sensors are further made energy-aware which supports an agent (i.e. remotely accessible function) which uses low data rate wireless transmission, reduced duty cycle and uses data aggregation to enhances the battery life of the connected sensors. This design has to address the stack state machine to control the network messages and also integrate at the physical layer with different radios and the connected sensors which have real-time monitoring requirements. The underlying cooperative OS allows dedicated tasks for data collection and control of attached sensors. We use the seven layer OSI model for reference due to the tiny nature of the sensors the numbers of effective layers are reduced to mini four namely application, network, data-link and physical layers. Our protocol is dependent on the functionality of the target sensor as some of them need more data aggregation-specific requirements and others need to handle data routing needs. So the ROM and RAM requirements are the qualifying factors to tailor the functionality of the network layer or a scaled down bare minimum CRF-STACK [1] implementation for more passive sensors.

As in any network environment, reliability and robustness are important part of the network design, we need to address self configuration of sensor networks as these are non-IP based and ad-hoc in nature. The existing body of research is currently focused on distributed infrastructure less multi-hop, clustering [5] and power-aware routing algorithms which have complete knowledge of the network but does assume any operating system complexity. In reality this assumption may not be true as the sensors need to be built from ground up with a power-aware maintainable operating system. In this work we enhance the previous work on LEACH by actually giving each sensor a reuse probability and measuring the mean residual before failure (loading per sensor) with varying percentages of cluster heads. Also we present a MAC level protocol CRF [2] which has adaptive low-complexity routing based on variable transmit power network discovery to partition the network into functional zones. The simulating the whole network (up to 100's of nodes) to perform self-discovery, partition of the large network into functional zones, assign hierarchical network addressing and application targeted routing.

The data transmission uses the B-tree with $|N|$ formed with all the sensor nodes and each edge $|E|$ of radius calculated by the CRF protocol. We show that the routing complexity cannot be balanced by increasing the resource availability but can actually degrade the expected performance, so there exists an ideal or fixed number of routers which need to be configured for any wireless sensor network to maximize its lifetime without failure for a given transmission throughput.

The rest of paper is divided into three main sections, section one compares the light weight CRF-STACK with the standard OSI model, section two shows the functional implementation of CRF-STACK layers and the transaction model and section three shows the simulation routing performance results of the CRF protocol with and a fault recognition algorithm to detect false alarms due to faulty readings and concludes with hardware resources it needs to deploy on the target platform for a passive sensor or controllable implementation of the CRF-STACK.

2. CRF and Environmental Partitioning and Deployment

Control radius flooding (CRF) is a method for recursively (steps 1, 2, 3 in Fig. 1) subdividing an ad-hoc sensing region into zones sets by individual sensor flooding. The subdivision gives rise to a representation of the ad-hoc static sensors by means of a tree data structure known as CRF tree. It uses two criteria to make if energy efficient. The first it uses the minimal power needed from node-0 (coordinator-C) to flood its neighbors which is recursively repeated three times to form three forward zones joining the source to the distance sink. The second criteria is CRF uses a static cache (Zone 2) which for maximum energy efficiency needs to be 20% of the total number of nodes N. This split is shown in iteration 4 of the tree in green.

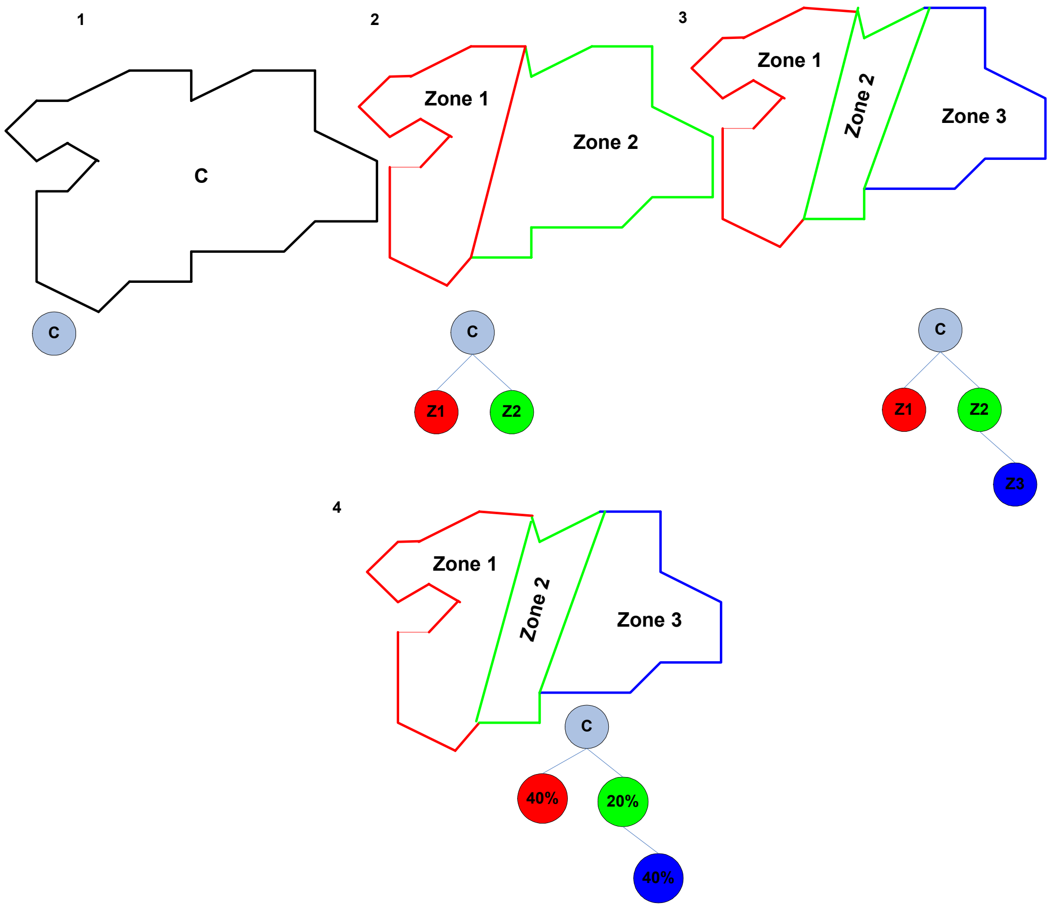


Fig. 1. Partition of the sensing region into functional zones using recursive CRF protocol and the percentage of nodes after complete topology discovery.

3. Open Systems Interconnection (OSI) Model

Open Systems Interconnection (OSI) model is a reference model developed by ISO as a framework of standards for communication in the network of different equipments. The OSI model defines the communication process into seven layers. The OSI model is capable of being used for wide area networks and, hence, it is more complex than what is needed for CRF-STACK. The stack features for the implementations of computer network and CRF-STACK protocols are compared in Table 1. Inspired by these unique requirements, we propose our protocol stack with four layers namely application, network, data link, and physical layer. In the proposed model, we compress the existing CRF protocol into the network layer and the data link layers. The upper three layers of the OSI model could be merged into one layer that is called application sensing layer which handles zone creation and data aggregation. The physical layer and the MAC layers implements the CSMA-CA protocol and a hardware abstraction layer (HAL) is implemented to use any type of radios and also to interface to any real-time sensors.

Table 1. OSI (Vs) CRF-STACK

Protocol Stack Layers	Implementation Type	
	Computer Network protocol stack	CRF
Application	Software	Hardware/ Software
Presentation	Software	
Session	Software	
Transport	Software	
Network	Hardware/Software	Hardware
Data Link	Hardware/Software	Hardware
Physical	Hardware	Hardware
OS-Kernel HAL	Desktop	HAL/Real-time Ext.

4. Design of Protocol Stack

Each layer of the proposed protocol stack is divided into both transmit and receive only parts. Stack size of at least 55Kbytes is required for a full CRF-STACK and < 20Kbytes for a passive sensor.

4.1. Application and Sensing Layer

This layer is the highest layer of the protocol stack. In a CRF-STACK environment, each sensing node is pre-configured (hard coded) to comply with its ROM and RAM sizes and the zones they are located to be a fully functional aggregator, a router or a tiny passive sensor. This layer implements the CRF zoning to split the whole network into three functional zones. Zone-one has tiny passive sensors and uses a single hop to connect to the parent data aggregator (which is normally considered as node-0), zone-two has routers with full CRF-STACK capable of acting as a cluster head [5] and zone three has tiny passive sensing devices. The monitoring only stack has real-time extensions to the OS scheduler to manage dedicated sensing activity to periodically collect the sensed data to be communicated over the stack.

4.2. Network Layer

The most important responsibility of this layer is routing of sensed data to a central aggregator. To accomplish the design goals of supporting a hierarchical tree routing with zone hopping (multi-hopping), a bare minimum protocol needs to be defined. The network layer also can handle large amounts of nodes with low latencies and without the use of high power transmitters. To add a new protocol on top of CRF one has to know the data flow and extend the appropriate addressing to support large number of nodes in a zone partitioned network. For simplicity to satisfy the data rate of the application we assume a traffic model which, at an application defined rate, updates the newly read sensor values and routes to a central aggregator. We first choose the addressing scheme. In this hierarchical topology we use two types of addressing: one is a unique 64 bit long address and the other a 16 bit short address. The addressing mode is source/destination identifier for peer to peer communication; typically the parent and the central aggregator have long addresses and the children are assigned short addresses. The long addresses are unique over multiple networks as each network can have up to 216 (65,535) sensor nodes. Thus a single network is always addressed in three zone format, parents (long address), siblings (long address) and children (short address).

To address application-specific data flow with a basic transaction (data aggregation schedule) to accomplish these on a wireless medium, where only one node can transmit data at a given time, we need to see the data flow using a beacon and a beacon-less system. A beacon is generally used to detect new sensors on the network and register them as part of the network or to allow existing sensors to update their new data. The shorter the beacon time the shorter is the node detection time of the overall network. But as the beacon period is reduced, more capacity is used for beacon transmission. As all the data collecting sensors are located in zone three and zone one we need a beacon based system for scheduling the sensors to wake up and collect the new data and send it to its parent. Also, this beacon system can discover new sensors and assign them a short address.

In a sensing application there are two types of needs: in the first case the data needs to be gathered only when needed and the rest of the times sensors are put to sleep saving valuable battery power. In the second case the application has some measured threshold such as if is there is a change in measured-delta then only the data is forwarded to the central aggregator thus saving redundant packets. Both these transaction needs can be addressed: the first uses a beacon based time slot the other uses non beacon based data trigger to forward the packets.

Having decided on the basic structure of transactions to enhance CRF, one needs to define a packet format for transaction between sensor and cluster heads as shown in Fig. 3. This message format is defined in Fig. 2 to suit a low data rate, low latency requirement. To keep it light weight, we define a simple implementation. GENFRAME definition has the protocol CRF data packet as well as MAC standard envelope which we call as CRFPKT.

1. Protocol version(one byte)
2. Flags (one bit each)
3. Command
4. Response
5. Error
6. Sequence and acknowledgement
7. Data length (two bytes)

3.2.1. Packet Format

Ver	Flag	Seq	Ack	Dlen	Data

Fig. 2. Simple protocol packet for CRF.

```
typedef struct {
CRFSTACKHDR h;
BYTE data[CRFSTACKPDLEN];
}CRFPKT;

typedef struct {
GENHDR g;
BYTE buff[MAXGEN];
} GENFRAME;
```

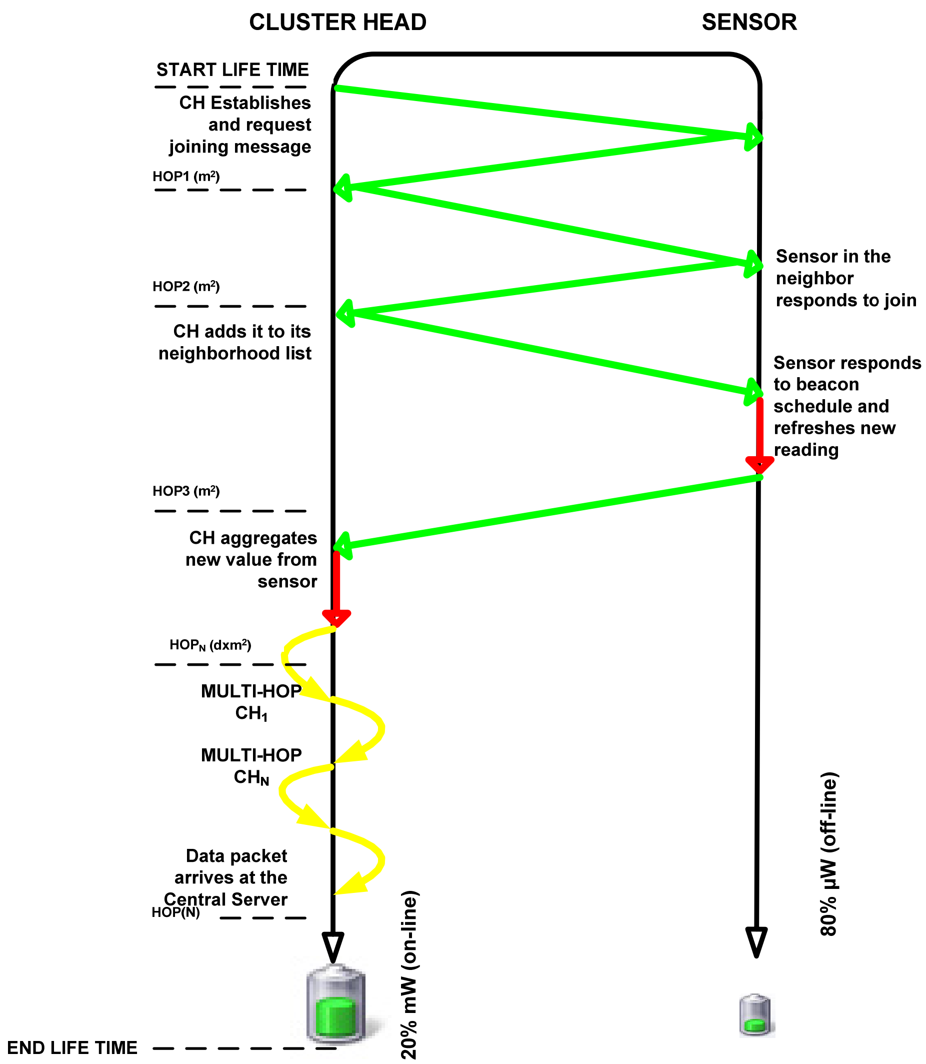


Fig. 3. Figures shows message sequence during routing on the left and energy dissipation during data aggregation on the right per node.

4.2.2. Internal Storage

Having fixed the external appearance of the CRF-STACK ten byte packet (CRFPKT) one needs to standardize on the internal storage format. For a 10Kbps channel capacities it can at most send 50 header packets per second. It may be recalled that since one of the main goals is to be compatible with all types of radios and existing wireless standards, we need to assign a generic frame type to handle which type of super frame it is. The super frame is followed by a block of data up to the maximum size possible. This could be integrated into the emerging family of standards in wireless sensor network protocols for interoperability (GENHDR) such as IEEE 802.15.4.

4.2.3. Addressing

Since this layer assigns hierarchical addressing, we need to incorporate it into the existing packet format as defined in Fig. 4 to route uni-cast, broad-cast and multi-cast operations. We have already defined two types of addressing, long and short addressing. To get the long address of the parent the child nodes can query the sibling and its next multi-hop parent to resolve the complete destination path.

Dest	Srce	Pcol	Ver	Flag	Seq	Ack	Dlen	Data

Fig. 4. Addressing CRF routing.

From Table 2, the usage of short and long addressing used by CRF-STACK protocol can easily be understood.

Table 2. Addressing mode between motes.

From	To	
123456789ABC	FFFFFFFFFFFF	Broadcast
3456789ABCDE	123456789ABC	Parent to sibling
123456789ABC	255	Parent to child(short address)

4.4. Data Link Layer

This layer is cluster aware and holds the neighborhood table as this has the entries of all the children (zone III). The layer has full knowledge and control of one hop neighbors. As shown in Fig. 1, a beacon based refresh mechanism is used to keep track of all the connected sensors. The main functionally of the layer is discovering new sensors, scheduling data aggregation for all the child nodes and power management by using the sensor nodes to be on (duty cycle) when acquiring new data defined by an application beacon rate.

The MAC implements the localization, mobility and neighbor list. On top of these it does power control i.e. the amount of transmitted power range it needs to assign for a given sensor node as shown Fig. 5 which is calculated by CRF on-line clustering algorithm. Currently since there is no standard, it can be anywhere between 10-100 meters which is practical for indoor deployment but for high density sensor networks it needs to be specially adjusted which is called special density of the covered region. A good topology discovery algorithm is to find the density of the network and use flooding and create a neighbor list. CRF implements control flooding i.e. if a node is already in the neighbor list it can flood within its RF range but a newly discovered node cannot until it is added to the list for the next iteration of flooding. This process is repeated three times as our need is to split the topology into three separate zones with always connected end zones with a caching middle zone. At the end of the discovery phase the complete range is found out which is a single hop from the farthest node to the central aggregator and the neighbor list contains all the address of the single hop parent and all the siblings have the addresses of the child nodes. This flooding is performed only during the initial discovery phase typically started by FormNetwork-API (Fig. 10).

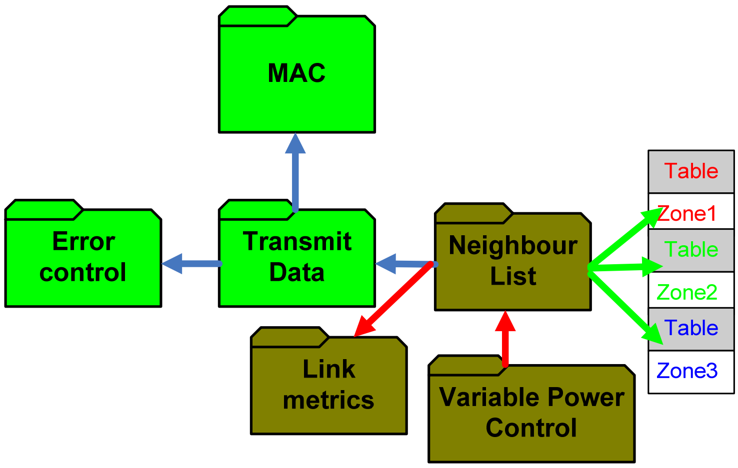


Fig. 5. MAC and its differential radio power control dependencies.

4.4. Physical layer

Physical layer consists of spread spectrum radio technology which transmits a signal to a much wider range of frequency band. To a narrow band receiver, the transmitted signal is impossible to detect as it appears as low-level noise. However, a wide band receiver can monitor the whole frequency band and detect changes. The overall goal of this layer is to use an emerging standard to make the radios interoperable.

4.5. Hardware Abstraction Layer (HAL)

This is a BIOS (Basic input-output) dependent layer which controls the input, output LEDs and sensors connected to each mote. As the stack size is of a critical concern no additional tasks are running inside the motes so the network stack allows call back functions to control the connected sensors and acquires the readings without OS buffering. The target specific API's are compiled for each build which implements specific hardware interfaces.

4.6. Simulation and Cross Layer Optimizations

The protocol stack used by the central aggregator is dependent on all the underlying layers of the stack that contains software and hardware only implementations. Since the hardware layers are non-programmable, it is best to use the specification for low cost, low memory and low data rate requirements. In the case of software, layers starting from the application sensing are very closely dependent on the type of application specific traffic and the available bandwidth which leads to the term cross layer optimization in sensor network applications. As the topology of CRF is static, once discovered it seldom changes making it easier to tune the parameters for addressing large sensor networks, multi-hop tree routing and data aggregation model for localized sensing. By simulation which implements the stack layers and a battery model (except the channel access protocol), we show that these parameters achieve optimal savings over the complete life-time of the sensor network when routing data packets. The simulation results are compared on two optimal criteria. The first is the maximum number of rounds which can be achieved by a routing algorithm which is shown in Table 3 and then the same results are extended to find residual energy dissipation which calculates how evenly does the distributed algorithm fair in terms of energy drain per node (reliability) as shown in Fig. 6 as opposed to peak performance (max rounds) in our previous case.

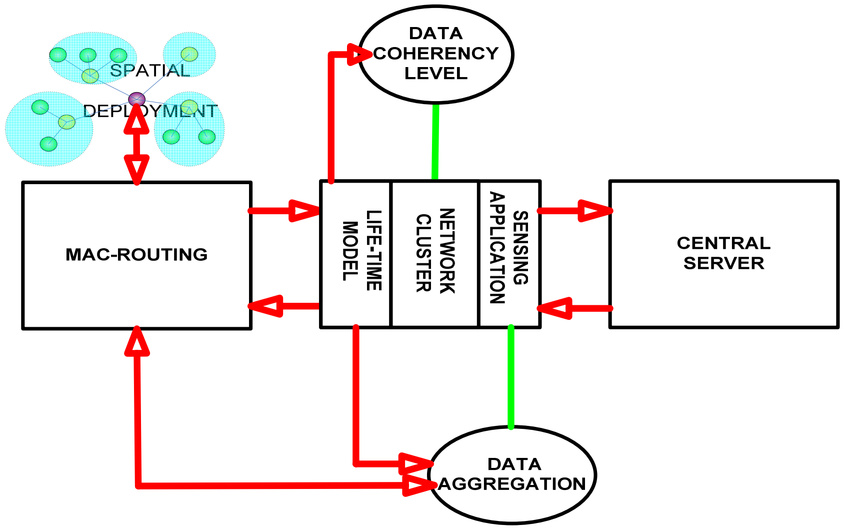


Fig. 6. MAC and its differential radio power control dependencies.

Table 3. Routing results for varied percentage of cluster and their residual energies.

Algorithm	Percentage of clusters (reusability)	Round the first node dies (max lifetime)	Residual Energy Dissipation (Collaborative factor) (Convergence↓)
LEACH-S	5%	10,736	27.90%
(Random Probability, 0.2 CH & 0.8 nodes)	10%	8992	38%
	20%*	9681	36%
	30%	8535	46%
	40%	8894	50%
	50%¥	10,836	49%
LEACH-E	5%	17,602	0.97%
(Ø - Threshold)	10%*¥	15,604	0%
	20%	15,351	1.74%
	30%	15,395	15%
	40%	13,824	32.50%
	50%	7932	64.10%
CRF	Zone1Zone2Zone3		
(Fixed caching 1/3 rd)	5% 30% 5%	14,580	22.17%
	10% 30% 10%	14,234	8.79%
	20% 30% 20%*	15,227	6.04%
	30% 30% 30%	14,585	10.22%
	40% 30% 40%¥	17,214	7.45%
	50% 30% 40%	14,615	20.01%

3.7. Routing Comparison of Energy Efficiency Versus Cluster sizes

The wireless sensor simulator [6] allows picking the number of cluster heads in each simulation run and the type of distributed algorithm used such as LEACH, LEACH-E and CRF. In this experiment for each lifetime run (up till the 1st sensor dies) for a routing algorithm the percentage of cluster heads is gradually increased from 5% up to 50%. The results are plotted as seen in Fig. 7. LEACH-S which is the standard [5] implementation of the paper in 2001 from MIT which is shown in Table 3 as expected it linearly increases as the number of cluster heads increases. But in the case of the energy adapted version LEACH-E and CRF it is optimal when the percentage of cluster heads are at 5% and 40%. Here we cross-verify the results and show that for energy efficiency in minimum loading per node in the case of LEACH-E and CRF and converges without error at N <=20 as shown in Fig. 7.

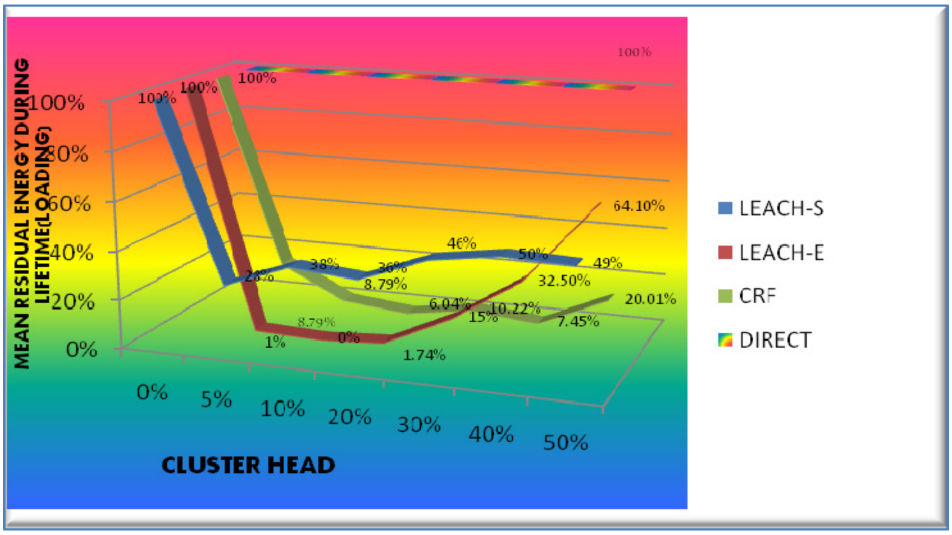


Fig. 7. Lab results shows residual energy dissipation impact loading on the whole network for distributed routing algorithms compared to direct transmission(always 100% loading).

The adaptive versions of LEACH are LEACH-E for energy centric threshold and CRF which uses a static cache. In both the cases loading is minimal (Fig. 6 shows the data points in percentage of remaining residual power) and highly fault tolerant when the percentage of cluster heads are set to 20% as shown in figure (0% for LEACH-E and 6.04% for CRF). This result highlights the fact that the energy dissipation is network size invariant and always divides the sensor nodes into 80-20 rule which is 80% of the nodes are idle and 20% does the real routing.

4.6. Routing Comparison of Energy Efficiency Using Multi-hop Algorithms

These families of routing algorithms are non-cluster based. To verify with other routing algorithms which are non cluster based as simulated before we use a multi-hop based routing which implements the following forward one hop routing algorithms. These algorithms are based on each hop logic and they decide on how to branch or navigate the densely connect mesh of the sensor network. The can be further divided according to path logic used, minimum spanning tree which visits a node only once and has no cycles, Power-aware hop which uses the most non-used path with high remaining residual energy and the short-path which takes the quickest path available between source to sink. Fig. 8 shows that when compared to CRF (cached based routing) the multi-hop version does far below the expected values in terms for maximum number of rounds completed. The MST comes closest to CRF followed by worst cases results in MH-PA and MH-SH.

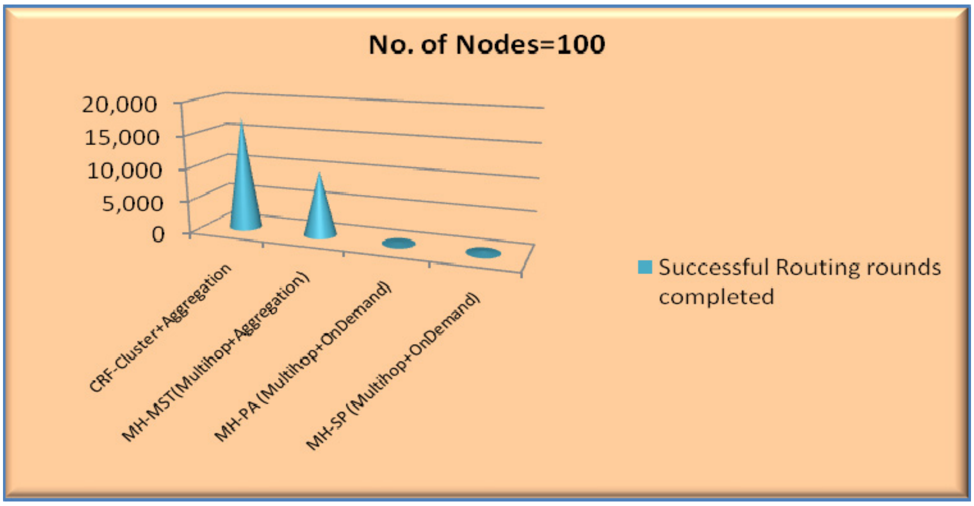


Fig. 8. Lab results shows number of rounds for clustering, multi-hop and on-demand algorithms.

5. Fault Recognition Model for Sensor Data Aggregation

The model uses Bayes posterior estimation by introducing two types of expected errors.

$$Posterior = \frac{likelihood \;\; x\, prior}{Evidence} \tag{1}$$

It is true, however, that the sensor measurements in the operation region are spatially correlated (since many environmental phenomena are). The first namely the electronic sensor faults which are uncorrelated [3] with the sensor measurement and the other which is based on the total unattended life-time of the sensor network or simply load balancing errors. One can define the total unattended life-time of the sensor network as

$$Unattended\ Life-time = No.\ of\ routing\ rounds\ before\ the\ 1st\ sensor\ dies + No. of\ remaining\ routing\ rounds\ before\ the\ last\ sensor\ dies$$

Using equation (1) we can estimate the probability before the 1st sensor dies given by equation when it is tamely faulty.

$$P_{good} = \frac{(1-p_1)\frac{k}{n}}{(1-p_1)\frac{k}{n} + p_1(n-k)} \tag{2}$$

$$P_{bad} = \frac{p_1(n-k)}{p_1(n-k) + k(1-p_1)} \tag{3}$$

We will say that we are trying to find the correction c, out of all possible corrections, that maximizes the probability of c given the original measurement M:

$$P_2 maxc = P\left(\frac{c}{M}\right)$$

By Bayes Theorem this is equivalent to

$$P_2 maxc = P\left(\frac{M}{c}\right)P(c)$$

$P(c)$ the probability that a proposed correction c stands on its own. This is called the correlated cluster model. $P\left(\frac{M}{c}\right)$ the probability that *M* would be measured by itself when the network meant *c*. This is the error model. Pmaxc, the control mechanism, which says to enumerate all feasible values of *c*, and then choose the one that gives the best combined probability score. p_1 can be corrected locally at the sensors and p_2 can be corrected at the host as it needs more processing power.

Where p_1 is the % of faulty (e.g. 2%) sensors and k is the number of good sensor readings and n is the total number of sensors in the cluster. It at least needs two or more good sensors to recognize the fault. If it is widely faulty then equation (3) gives the best estimate. The second type of sensor error p_2 happens due to the type of clustering algorithm used (e.g. LEACH) which re-uses the sensors resources and eventually drains it out of battery power. This stage of the sensor life-time happens when the 1^{st} sensor dies due to overuse. If the total number sensors in the network in N (large), then the probability of the error for the remaining part of the lift-time will be 1/N after the 1^{st} sensor dies, applying in equation (1), (2) we get the posterior estimate of the sensor reading for correlated sensor faults. P_2 estimate after the 1st sensor dies and prior probabilities are preserved.

Similar to life-time definition the sensor faults can be modeled as tamely faults and widely faulty in the respective regions of their life-time cycle as shown in Fig. 9. This model defines an overlap criteria [4] using membership functions which take value between [0,1]. These are four membership functions defined one for the un-correlated faults and other three for each clustering algorithms compared. With this a linguistic variable is defined with values [0,1] for tamely faulty and widely faulty. The notion of erroneous high values readings from faulty sensors can be interpreted using the degree of membership function it takes in the underlying rule based model.

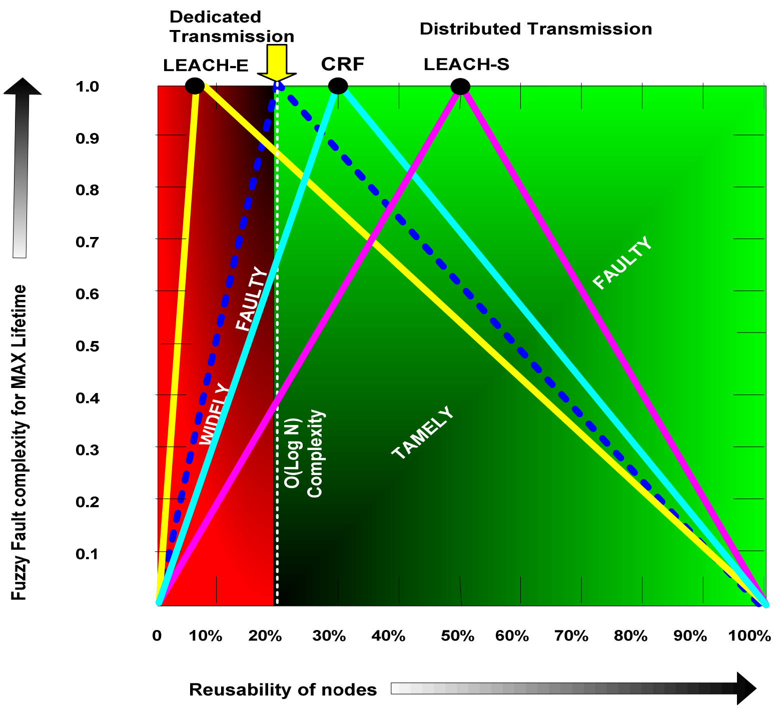


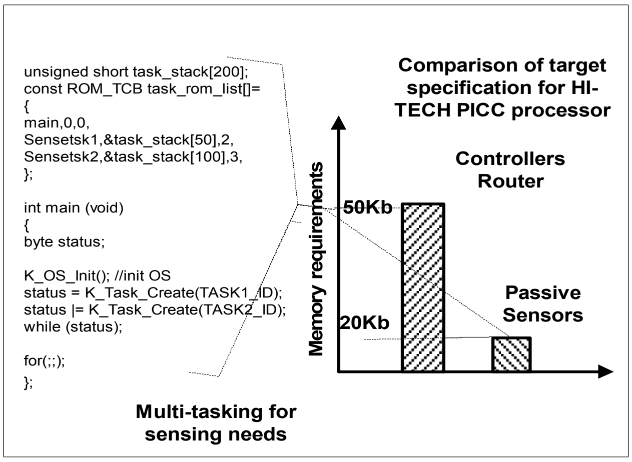
Fig. 9. Fault recognition Overlap function for data aggregation using membership function.

6. Environmental Measurement Real-Time OS

To implement the CRF-STACK for a given target embedded processor we need to comply with the available ROM and flash memory resource availability. The current stack size including HAL layer takes up to < 50kbytes. The comparison for specific compiler and functional requirements and its target sizes are seen in Fig. 10. The functional differences and resource requirements needed to store neighbor tables and implement dedicated sensor tasks are discussed in section 7. Tools needed to configure and program an embedded system are a target based compiler which means that one needs an M×N number of compilers where M is the number of target processors and N is the number of supported languages. As this is a huge number we standardize on ANSI-C for portability purposes as most of embedded compilers support this low-level language. This makes use of M compliers to support all available sensor targets. The parameters which are target dependent are listed below in Table 4. Most of the sensors have specific ROM, RAM and additionally a flash interface built in. The current architecture allows to add a multi-tasking OS [5] which could be ROM resident with most of it kernel services and runtime libraries. As CRF-STACK are state machines and could be adapted to be re-entrant (if the application must run the FSM from multiple independent threads and the FSM code must only process a single transition and then return).

Table 4. Energy-aware stack simulator.

Protocol Stack Layers	Implementation Type	
	Computer Network protocol stack	CRF (Energy Usage)
Application	Software	Hardware/Software 80% µW(off-line)
Presentation	Software	
Session	Software	
Transport	Software	
Network	Hardware/Software	20% mW (on-line) Embedded
Data Link	Hardware/Software	80% µW (off-line) Embedded
Physical	Hardware/Software	80% µW (off-line) Hardware
OS-Kernel HAL	Desktop OS	80% µW (off-line) HAL/Real-time Ext.



Protocol Stack Layers	CRF Stack APIs.	
	Fully functional stack	Monitoring only stack
Application	FormNetwork()	Join Network()
Network	CreateZones()	StackBeacon()
Data Link	CRF()	CRF()
Physical	IEEE Standard	IEEE Standard
OS-Scheduler HAL	SetLED()	SetLED() CreateSenseTsk1 CreateSenseTsk2

Fig. 10. Stack size for different sensor footprint needs and the program for tiny multi-tasking.

With these modifications some of the static data can be loaded into ROM and the remaining could be fit into available RAM. The multi-tasking feature can service sensor events or periodically aggregate data which could be queried by the top level application and send over the stack. The complexity of the program and its resource requirements is dependent on the routing, aggregation algorithms or data logging periodicity needs.

7. Benefits of Energy-awareness in the OS Measurement

Shown below are the energy management parameters available to the simulator at each level.

1. TOPOLOGY LEVEL: Ø-threshold based cluster head selection (Caching)……
2. TOPOLOGY LEVEL: Optimal number of clusters (Power Law)………………
3. TOPOLOGY LEVEL: Density of sensor network (K-neighborhood distance)…
4. TOPOLOGY LEVEL: Routing overhead – $O(logn)$…………………………… Classification
5. DATA LINK: BEACON duty cycle, synchronization---------------------------
6. DATA LINK: Data aggregation & compression (Lossy Model)--------------------
7. DATA LINK: Adjustable Transmit range (Redundancy=less power) --------------
8. PHYSICAL LAYER: Low bandwidth, Data rate/ bit---------------------------------
9. OS-KERNEL: Sensing scheduler (less contention=less power)--------------------- Sensing
10. OS-KERNEL: IDLE time scheduler(less usage=less power)-----------------------
11. OS-KERNEL: Low footprint(low memory reqd.=less power) ---------------

8. Conclusion

In this paper we have addressed how to implement a tiny protocol and a portable stack for R&D and simulation of large sensor networks which uses cluster based routing protocols and multi-hop protocols. The network layer and the data link layer use all the cross layer optimization to achieve specification requirements and extends the real-time kernel services to implement time critical and sensor specific tasks to achieve a better design. Each of these routing categories clustering and multi-hoping finds specific application advantages based on the type of deployment one is periodic and other mostly reactive networks. Also it models a cluster fault recognition algorithm to better predict and rectify false alarms when a routing algorithm does not converge in a simple lifetime and erroneous sensor measurements. We also prove from the results that the resource problem in sensor network is scale invariant and converges when N<=20%. By uniquely dividing the load and by adjusting the cluster size we could extent this reliability model to all the previous work on sensor network into fuzzy model to predict the max lifetime to distributed complexity of each power-aware algorithm.

Acknowledgements

Authors are grateful to Dept. of Science and Technology-DST, Govt. of India, for supporting the work with a grant. Also like to thank M.S. student Agarwal .M for helping us on the interoperability of network on chip and Dr. Bertrand from CCT, Switzerland for identifying a suitable application for real deployment.

References

[1]. Software Stack Architecture for Self-Organizing Sensor Networks, Vasanth Iyer, Rama Murthy and M. B. Srinivas- ICST 2007, Palmerston North New Zealand.
[2]. Vasanth Iyer, Rama Murthy, M. B. Srinivas, Information Processing of Wireless Sensor Networked Motes by Harvesting Residual Power, *The Second IEEE International Workshop on Next Generation Wireless Networks 2006* (IEEE WoNGeN 2006).
[3]. Efficient and Fault-Tolerant Feature Extraction in Wireless Sensor Networks Bhaskar Krishnamachari and S. Sitharama Iyengar.
[4]. Dr. Ramamurthy, Distributed Wireless Sensor Network Architecture: Fuzzy Logic based Sensor Fusion, Vasanth Iyer, *EUSFLAT*, Sep 11-14th 2007, Ostrava, Czech Republic.
[5]. Wendi Heinzelman, Hari Balakrishnan, LEACH (Low Energy Adaptive Clustering Hierarchy), Anantha Chandrakasan, 2001.
[6]. Simulator for download at http://www.geocities.com/ids_lab/crf.zip

___

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information