A Cooperative Internet of Things (IoT) for Rural Healthcare Monitoring and Control

Vandana Milind Rohokale
Center for TeleInFrastuktur,
Aalborg University, Denmark
vmr@es.aau.dk

Neeli Rashmi Prasad
Center for TeleInFrastuktur,
Aalborg University, Denmark
np@es.aau.dk

Ramjee Prasad
Center for TeleInFrastuktur,
Aalborg University, Denmark
prasad@es.aau.dk

ABSTRACT *Internet of Things (IoT) concept enables the possibility of information discovery about a tagged object or a tagged person by browsing an internet addresses or database entry that corresponds to a particular active RFID with sensing capability. It is a media for information retrieval from physical world to a digital world. With cooperative wireless communication, the wireless node entities can increase their effective quality of service (QoS) via cooperation. In developing countries the death rates due to lack of timely available medical treatments are quite high as compared to other developed countries. The majority of these deaths are preventable through quality care. This paper proposes a cooperative IoT approach for the better health monitoring and control of rural and poor human being's health parameters like blood pressure (BP), hemoglobin (HB), blood sugar, abnormal cellular growth in any part of the body, etc.*

Keywords: Internet of Things (IoT), Radio Frequency Identification (RFID), Cooperative wireless communication (CWC), Quality of Service (QoS).

I. INTRODUCTION

World Health Organization (WHO) defines the maternal mortality as the death of a woman while pregnant or shortly within 42 days of termination of pregnancy. An indirect maternal death is a pregnancy-related death in a patient with pre-existing or newly developed health problems during pregnancy. According to UNICEF's 2003-2008 report, the maternal mortality ratio is 2.5%. Illiterate women in the rural part of developing countries tend to ignore their health problems due to either poverty or unawareness of the health issues [1].

The World Health Organization (WHO) and UNICEF report states that each year 585,000 women die from causes related to pregnancy and childbirth [2]. Women from any part of the world can develop complications, but women in developing countries are much less likely to get prompt adequate treatment, and are therefore, more likely to die. In some countries of Africa, it is estimated that 1 in 7 women die of complications of pregnancy or delivery, compared with only one woman in several thousands in Europe and North America [3]. The majority of cancer related deaths are due to late detection of the abnormal cellular growth at the last stage. If this abnormal cell growth is detected in the primary stage of cancer, many lives can be saved.

IoT supports many input-output devices and sensors like camera, microphone, keyboard, speaker, displays, near field communications (NFC), Bluetooth, accelerometer, etc. The main component of the IoT is the RFID system. RFID can automatically identify the still or moving entities. The main aim of IoT is to monitor and control objects via Internet. The idea behind it consists of interconnecting objects by sensors and monitoring via the Internet. IoT follows the Metcalf's law which states that the value and power of a network increases in proportion to the square of the number of nodes in the network. For the future Internet and IoT, it is very much essential to keep track and control the immensely growing number of networked nodes so that it will be possible to network them with everyday objects in homes, offices, buildings, industries, transportation systems, etc. in cost-effective and valuable way [4].

IoT refers to a wireless and self configuring network among objects such as household applications as shown in Figure 1. The exponentially increasing quantity of objects/things around us needs proficient interaction schemes allowing easy access. Personal Area Network (PAN) including IoT is an unpredictable and spatially local network that includes every object a person should interact with. The nodes of the PAN are the hardware constrained devices. These nodes usually have a few kilobytes of volatile as well as relentless memory, a CPU with few MHz frequency, limited energy, and stumpy throughput physical links like Bluetooth, Zigbee, USB, Wi-Fi, etc [5]. Application areas of IoT include: Manufacturing, Logistics, Retail, Energy and utilities, Intelligent Transportation system, Environment

Monitoring, Disaster Management, Healthcare, Home management and monitoring, etc. This paper is organized as follows. Section I introduces motivating scenario, section II introduces related work and summary. Section III discusses the proposed cooperative IoT model and section IV discusses and proposes the system model. Section V gives the simulation results with the quantitative analysis and finally section VI summarizes the paper.

Figure 1. Conceptual Structure of IoT

II. Related works

In CWC, several nodes work together to form a virtual array. The overheard information by each neighboring node or relay is transmitted towards the sink concurrently. The cooperation from the wireless sensor nodes that otherwise do not directly contribute in the transmission is intelligently utilized in CWC. The sink node or destination receives numerous editions of the message from the source, and relay(s) and it estimates these inputs to obtain the transmitted data reliably with higher data rates [6].

The cooperative communication mechanism is more applicable to AdHoc wireless and wireless sensor networks as compared to the cellular networks [7]. Here, each node acts as both a user (source) as well as relay. In cooperative resource allocation, each node transmits for multiple nodes. Opportunistic Large Array (OLA) is nothing but a cluster of network nodes which use active scattering mechanism in response to the signal of the source called leader. The intermediate nodes opportunistically relay the messages from the leader to the sink. OLAs are considerably flexible and scalable in nature. For cooperative transmission, OLA selects the nodes which have the received signal SNR above some threshold figure and since the resonance generated by relay nodes carries the actual messages to the desired sinks without causing interference.

OLA utilizes the cooperative transmission of the AdHoc network nodes to reach back a far distant node or sink [8]. A-OLA-T is the alternating OLA with threshold. It requires slightly less than double the power of basic OLA but A-OLA-T doubles the network life compared to basic OLA. The OLA broadcasting is a spread spectrum technology and therefore it is possible to have multiple OLA networks transmitting simultaneously to the same remote receiver. A-OLA-T can offer a 17% life extension as compared to basic OLA technique [9]. Opportunistic Large Array with Concentric Routing Algorithm (OLACRA) includes more flooding as compared to basic OLA. With optimum ganging of levels, OLACRA yields the diversity gains upto 75% [10].

III. Proposed Cooperative IoT Model

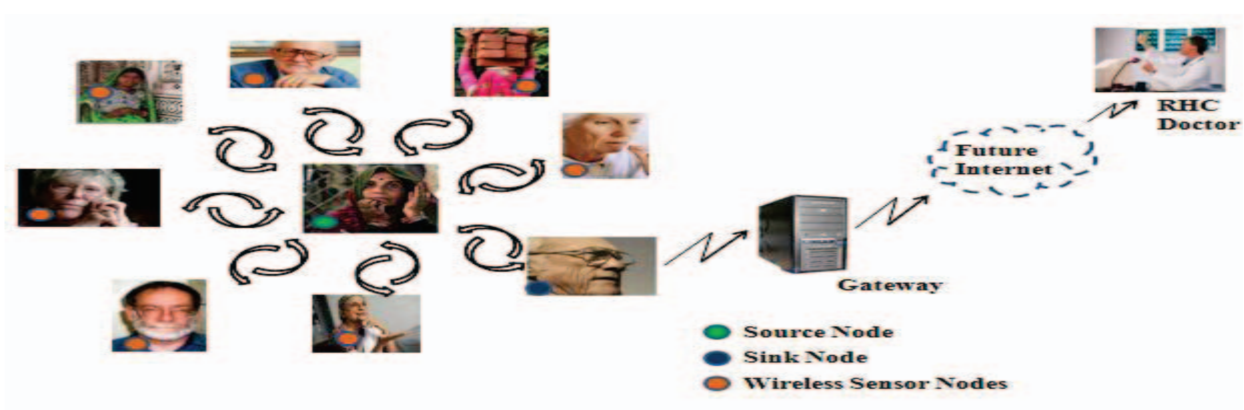

Figure 2. Cooperative IoT Model for Healthcare Applications

The rural healthcare centre (RHC) registered person will wear one active RFID sensor. Although the human beings wearing this sensor are illiterate, any changes in the normal parameters or alerts after exceeding certain values will be informed to patient as well as RHC doctor. Then the RHC staff will be able to reach the medical facility to the emergency patients.

The conceptual view of the proposed cooperative IoT model is depicted in Figure 2. This can definitely reduce the mortality rate in the rural areas of developing countries. The sensors wore by persons will form an OLA structure and the urgent information will be cooperatively routed through the sink node to the gateway computer and through Internet it will reach to the RHC doctor. Without Internet, the mobile network facility could be utilized to convey the information fastly. The health parameters which could be considered are Pulse blood pressure, Hemoglobin, Blood sugar, etc. In every village, one RHC should be active. The networked computer in the RHC will contain the data regarding health issues of the registered patients. The RHC monitoring person will update the data periodically regarding their doses and prepare the updated report. Table 1 indicates some parameters with their normal values. Any changes in these values will be reported cooperatively to the RHC doctor either in the form of alerts or message.

Table 1. Some health parameters with their normal values

Health Parameter	Normal Value
Blood Pressure (mmHg)	120/80
Blood Sugar (mg)	70-100 (Fasting value)
	Less than 140 (Post prandial)
Haemoglobin (g/dl)	11.5- 16.0

IV. SYSTEM MODEL

The consumer radio nodes which are half-duplex in nature are assumed to be uniformly and randomly distributed over a continuous area with average density ρ. The deterministic model is assumed, which means that the power received at a sink node is the summations of powers form each of the nodes. In this model, the network node transmissions are orthogonal. It is assumed that a sink can decode and forward a message without error when it's Signal to Noise ratio (SNR) is greater than or equal to modulation-dependent threshold λ [11]. Due to noise variance assumption of unity, SNR criterion is transformed into received power criteria and λ becomes a power threshold.

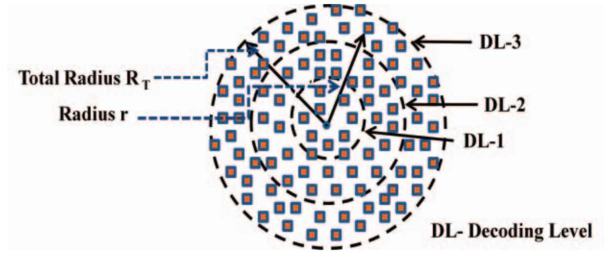

Figure.3. Proposed OLA structure for Numerical Analysis

Theorem: If $u \triangleq e^{(\lambda/\pi\rho P_r)}$ [13] and $u > 2$,

$$\text{then } r_k = \sqrt{\frac{P_S\,(u-1)}{\lambda\,(u-2)}}\left(1-\frac{1}{(u-1)^k}\right) \qquad (1)$$

$$\text{and } \lim_{k\to\infty} r_k = r_\infty = \sqrt{\frac{P_S\,(u-1)}{\lambda\,(u-2)}} \qquad (2)$$

For ($u \le 2$), the broadcast reaches to the whole network i.e. $lim_{k\to\infty} r_k = \infty$.

For ($u > 2$), the total area reached by the broadcast is limited i.e. $r_k < R_T$.

Instead of infinite radius, we are considering some practical scenarios where the radius is limited. For wireless LAN, the maximum radius covered is found to be approximately 100 meters. Wireless LAN, PAN and Bluetooth are the good candidates for limited radius scenario. Minimum node density requirement for particular transmission is obtained with the help of following equations.

$$\frac{\lambda}{\rho P_r \pi} > ln2$$

$$\frac{N_{total}}{\pi R_T^2} \ge \frac{\lambda}{\pi (ln2) P_r} \qquad (3)$$

where N_{total} is the maximum number of active nodes utilized for particular cooperative transmission for the radius R_T as shown in Figure 3 besides. Also for ($u > 2$), from eq. (3), the critical density could be obtained as follows,

$$\rho_{critical} = \frac{\lambda}{P_r \pi \ln\left(\frac{2\lambda r^2 - P_s}{\lambda r^2 - P_s}\right)} \qquad (4)$$

The Fraction of Energy Saving (FES) [11] with the OLA approach can be written as a ratio of

$$\text{FES} = 1 - \frac{\textit{number of active radio nodes utilized for cooperative transmission}}{\textit{Total number of nodes in the OLA network}} \qquad (5)$$

978-1-4577-0787-2/11/$26.00 ©2011 IEEE

Due to the unity noise variance assumption, the received power becomes received signal to noise ratio (SNR) [12].

$$\text{SNR=Prx=}\ \frac{\overline{P_r}}{d^2}=\frac{\rho Pr}{d^2} \quad (6)$$

$$\text{SNR=}\frac{NPr}{pi\ r^2 d^2} \quad (7)$$

SNR in Decibels (dB) = $10log_{10}$(SNR) (8)

Outage Probability is given by [13],

$$\text{Outage Probability} = \frac{1}{\sigma_{s,r}^2}\frac{2^{2R_S-1}}{SNR} \quad (9)$$

Where $\sigma_{s,r}^2$ = variance

R_S= Spectral efficiency

V. SIMULATION RESULTS

The goal of the experimentation is to reveal the fundamental tradeoffs of energy, latency, and throughput in S-MAC. All simulations of S-MAC are done using ns-2.34 where the energy model for S-MAC is updated. The radio power values used to compute energy consumption in idle, transmitting, receiving, and sleeping state are in accordance with the RFM TR3000 radio transceiver on Mica Motes. Simulation parameter and node configuration parameter set are given in Table 2 and Table 3 respectively.

Table 2. Simulation Parameters

Simulation Area	75mx75m
Energy Model	EnergyModel
Initial energy	100J
Transmitting Power	36.00mW
Receiving Power	14.4mW
Sleep Power	15uW
Transmission Range	100m
Number of Nodes	425

Table 3. Node Configuration Parameters

Channel Type	WirelessChannel
Radio Propagation Model	TwoRayGround
Antenna Model	OmniAntenna
Network interface type	WirelessPhy
MAC Type	SMAC
Interface Queue Type	PriQueue
Buffer size of IFq	50
Routing Protocol	DSDV

As shown in Figure 4, the fraction of energy savings is high for lower distant nodes. But as the threshold lamda goes on increasing, the fraction of energy savings (FES) value decreases. This lambda is nothing but the threshold value for that node to become eligible to decode the incoming information and retransmit it to the further nodes.

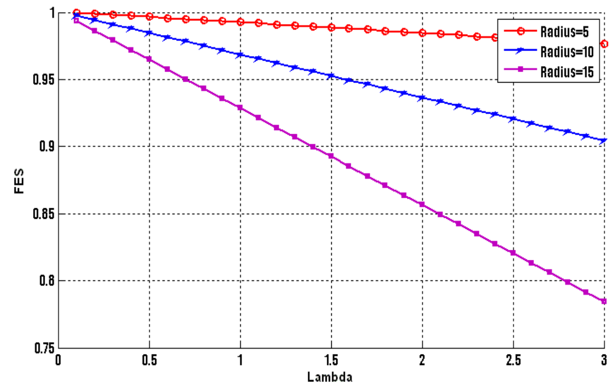

Figure 4. Fraction of Energy Saving versus Lambda

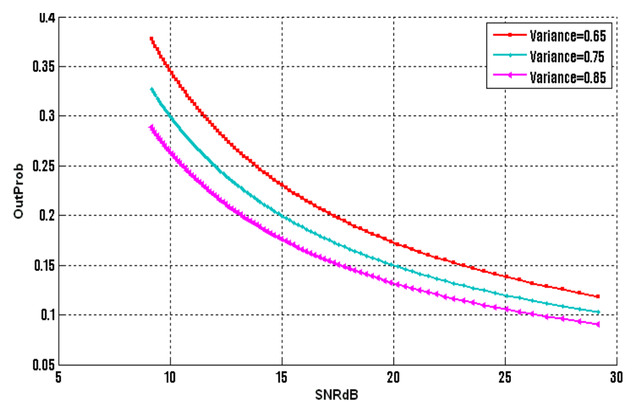

Figure 5. Outage Probability versus SNRdB

The graph is plotted in between Outage Probability and SNRdB as shown in Figure 5. For higher values of SNR, the outage probability values are considerably less as per the expectations. It shows the reliability of the proposed cooperative IoT model. Figure 6 shows the considerable decrement in the energy consumption. In Figure 7, the end-to-end delay graph is shown. It reveals from the plot that the end-to-end delay is slightly increased but the total communication delay can be reduced through cooperation. Plot of Figure 8 shows the significant improvement in the system throughput.

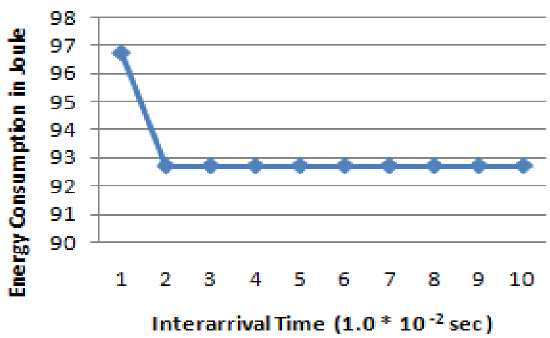

Figure 6. Energy consumption versus Interarrival time

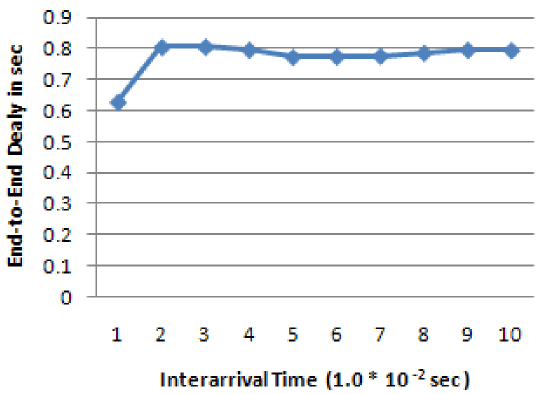

Figure 7. End-to-End Delay versus Interarrival Time

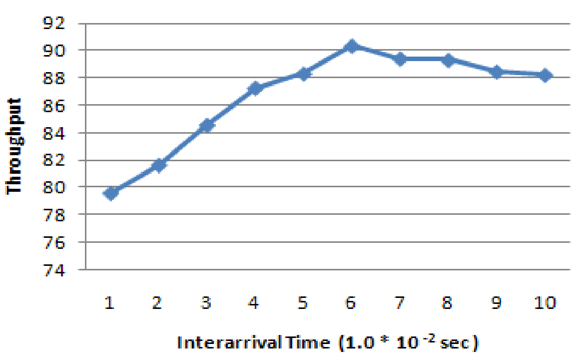

Figure 8. Throughput versus Interarrival time

VI. CONCLUSIONS

This article proposes a novel cooperative IoT approach for rural healthcare applications like safe motherhood program and many more. The distinctiveness of this algorithm is that node location information and high source transmit power for data are not needed. This approach can prove reliable for critical healthcare applications like continuous monitoring and control of health parameters of the human beings like, HB, BP, Blood sugar, etc. Energy savings of 57% achieved in this case is the first step towards green IoT. The outage behavior is almost same as that of amplify and forward technique but the energy savings achieved at the low threshold values is the added advantage of this system. The NS-2 experimentation has shown substantial enhancement in the system throughput. Simulation results reveal the tradeoff between energy consumption, latency and throughput in S-MAC operation. The novel aspect of this work will definitely lead towards standards and standardization in future. This work will be extended further for authentication and authorization in cooperative IoT systems.

REFERENCES

[1] Maternal Mortality Estimates 2008 by the WHO and UNICEF.

[2] World Health Organization/UNICEF. Revised 1990 Estimates of Maternal Mortality.

[3] WHO/FRH/MSM/96.11, UNICEF/PLN/96.1, April 1996.

[4] Robert A. Dolin, “Deploying the Internet of Things”, Proceeding SAINT ’06 Proceedings of the International Symposium on Applications on Internet.ISBN:0-7695-2508-3

[5] Simon Duquennoy, Gilles Grimaud, Jean-Jacques Vandewalle, “The Web of Things: Interconnecting Devices with high usability and performance”, International Conference on Embedded Software and Systems, 2009. ICESS. 25-27May2009,pp- 323 – 330.

[6] Manfred Bortenschlager, “Current Developments and Future Chllenges of Coordination in PervasiveEnvironments”, 16th IEEE International workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises, 2007.WETICE, 18-20 June 2007 pp:51 – 55.

[7] Pei Liu, Zhifeng Tao, Zinan Lin, Eiza Erkip, and Shivendra Panwa,”Cooperative Wireless Communications: A Cross-Layer Approach” IEEE Wireless Communications August 2006. Volume:13, Issue:4 pp:84 – 92.

[8] Aria Nosratinia, University of Texas, Dallas, Todd E. Hunter, “Cooperative Communication in Wireless Networks”, IEEE Communications Magazine 2004,Volume:42, Issue:10, pp:74-80.

[9] Ahmed K. Sadek, Weifeng Su and K.J.Ray Liu,” Multinode Cooperative Communications In Wireless Networks**”,** IEEE Transactions on Signal Processing, VOL. 55, NO. 1, January, 2007.

[10] Arvind Kailas, M.A.Ingram, “Opportunistic Large Array-Based Cooperative Transmission Strategies”, IEEE Transactions on Wireless Commun, August 2010, Vol-9, Issue:8, pp: 2415-2419.

[11] Vandana Rohoakale, Nandkumar Kulkarni, Horia Cornean, Neeli Prasad, "Cooperative Opportunistic Large Array Approach for Cognitive Radio Networks", 8th IEEE International Conference on Communications, June 2010, Bucharest, Romania.
[12] Vandana Rohoakale, Neeli Prasad, "Receiver Sensitivity in Opportunistic Cooperative Internet of Things (IoT)", Second International Conference on Ad Hoc Networks, August 2010, Victoria, British Columbia, Canada.
[13] Y. W. Hong and A. Scaglione, "Energy-efficient broadcasting with cooperative transmissions in wireless sensor networks," IEEE Tras. Wireless Commun., vol. 5, no. 10, pp. 2844–55, Oct. 2006.