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by N.Shyam Sunder Sagar and P.Chandrasekar Reddy
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Comparative Approach for Range Enhancing Energy Harvester (REACH) Mote Passive Wake-Up Radios For Wireless Networks

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Abstract— **In recent world, the wireless sensor networks are used intensively in many applications fields, these are used by scientific researchers to improve and accelerate the performance features of networks. The designs are very challenging and are sustainable, on the above these energy-dependent sensors are relied to run for long periods. These Sensor nodes are usually battery-powered and thus have very shorter lifetime. Here this paper, introduces a improved approach for wake-up radio devices called REACH (Range Enhancing Energy Harvester) Mote in place of general sensor nodes, here these nodes use the energy harvesting circuit in combination with an ultra-low-power pulse generator to activate and wake-up the motes in the wireless network. And this scheme helps in reducing latency without increase in energy consumption**

Keywords: Wisp, Energy-harvester, Data latency, OOM-MAC

1. INTRODUCTION

A sensor is an energy limited device that features capabilities of sensing and data processing, storing and transmitting. Wireless sensor network (WSN) are primarily used to monitor the environmental conditions like density, pressure, temperature etc. The WSN sensors are autonomous and they are randomly spatially distributed. The major problems in this type of network are energy consumption and latency. In-order to decrease the energy consumption, the radio sensor is put into sleep/idle mode. This strategy causes a delay for the transmission of the sensor readings to the base station and, hence the processing tends to reduce in real time.In order to decrease the power consumption various method have been introduced for battery limited sensor networks but none of the proposed method were acceptable as there is a trade-off between data latency and power consumption .

In this paper we would like to draw attention on various mechanisms involved with the passive radio receivers which include energy consumption and harvesting, range extension, hardware and software simulations, applications etc.,

2 Energy Harvesting and Range Extension

The Wake up ability of WISP (Wireless identification and sensing platform) has been increased by RF harvesting circuit In this section, the basic description and design of the energy harvesting circuit and its interfacing principles have been introduced. The properties of the circuit components have also been mentioned.

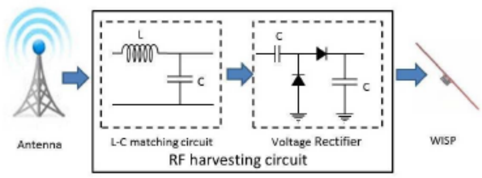

Fig. 1. Architectural view of the circuit and connections.

2.1 Selection of Circuit Components

The overall conclusion of our design is to maximize the energy conversion from the front-end antenna to the WISP-Mote. For this, we use a matching circuit for balancing the as shown in Fig. 1, input impedance is to be tuned in order to match with circuit load and the voltage rectifier(acting as multiplier) from the antenna side.

The multiplier circuit is based on the classical Dickson’s voltage multiplier circuit as shown in Fig 2. It has a number of stages which are connected in parallel. Each stage is a combination of a capacitor and a diode that are connected in parallel. The major advantage of the circuit is the capacitor arrangement with respect to each other. Because of this capacitor arrangement the effective circuit impedance is reduced. This helps in matching the antenna side and the load side in a simpler manner.

The diod es with lowe r volta ges

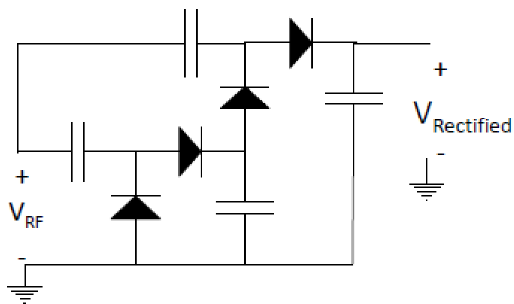

Fig. 2. Dickson diode based multiplier.

are more prefered as the voltage peak of the AC signal received at the antenna as basically less when compared to diode threshold.In order to cope up with higher frequency harvester circuits the diode switching time must be faster.The semiconductor-semiconductor junction is replaced by metal-semiconductor junction in the Schottky diodes. This allows the junction to operate much faster manner and gives a forward voltage drop as low as $0.15V$. Because of this HSMS-2852 specific diode is suitable for operating in the low power region which is typically considered at a range of power between $-20dBm$ and $0dBm$.

In harvesting circuit output voltage varies with stages of multiplier. It progressively reduces the current drawn by the load that in turn impacts the overall charging time.The output voltage of the circuit todrive is set at $915MHz$. The number of stages are set to 10 in order to ensure the sufficient voltage to the output circuit.

2.3 Design of EH-WISP-Mote

A special kind of mote by the name EH-WISP-Mote (Enhanced-WISP-Mote),which is a combination of energy harvesting circuit along with WISP mote is built in order to extend the wake-up range of the WISP-Mote, where the output of harvester circuit is connected to the power supply of WISP mote(+Vcc) and the ground pins of both harvester circuit and WISP mote are connected together. While the ability to perform ID-based wakeup is retained, this parallel connection of WISP mote and harvester circuit is used to extend the range of the wake up receivers.

3. Design of REACH-Mote

3.1 Wake-up Circuit

A sleeping mode which is in low power is used to awaken the Tmote sky node by either rising or falling edge and hence it is necessary to design a wake up circuit for triggering an interrupt onto the Tmote Sky node . As soon as the WISP receives wakeup signal WISP mote and EH mote make use of the MCU ,inorder to generate this pulse. Although an ultra low power microprocessor, MCU still consumes $250\mu A$ at $2.2V$ power supply.The wake-up range of the WISP-Mote is approximately constrained to 13ft [1] due to the limited energy harvested by the wake up radio receiver. To increase the range of the radio receiver it is necessary to construct a low energy consuming trigger generator when compared to the WISP.

The constraints included in building a trigger circuit are:
• Little energy must be consumed by the circuit in-order to increase the wake-up range.
• A rising/falling edge generated by the circuit must be capable of driving the Tmote Sky wakeup.

•The output voltage level of energy harvesting circuit is generally unstable and hence the trigger circuit must be able to work on variable voltages.

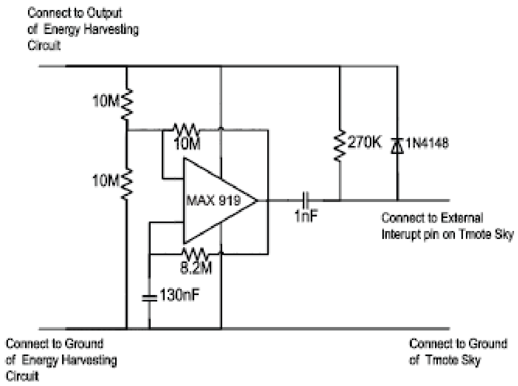

Fig. 3. Wake-up circuit of the REACH-Mote.

The trigger to the Tmote Sky mote [2] is given by the trigger circuit from Fig 3.This trigger circuit can generate a pulse of $100\mu s$ duration

once per second and can operating near a voltage ranging from 1.5-5V and the current consumed in this circuit, enough to be driven by the lower power receiving harvester circuit, is less than $1\mu A$, thereby achieving the design of low power wakeup receivers.REACH-Mote (Range Enhancing energy Harvester Mote) ,a wake up radio sensor node shown in Fig 4 is a combination of energy harvesting circuit, wake up circuit as well as Tmote Sky. Before the WuTx transmits the wake-up signal, REACH mote is tuned to the sleep mode i.e., the MCU on the Tmote Sky, which is an MSP430F1611, and the radio are put to LPM3 sleep mode [3] .Once the DC voltage sent by the harvester circuit is higher than $1.5V$, the wake up circuit starts generating the pulse which will trigger the mote and put the mote's MCU into active mode in $5ms$ [4].If there is any data to be transferred, then REACH mote starts the transfer else it goes back to sleep mode again
There is no drain of energy from the battery as the harvesting circuit powers the wake up circuit. Hence all the energy provided by the REACH mote is used for sensing and data communication.

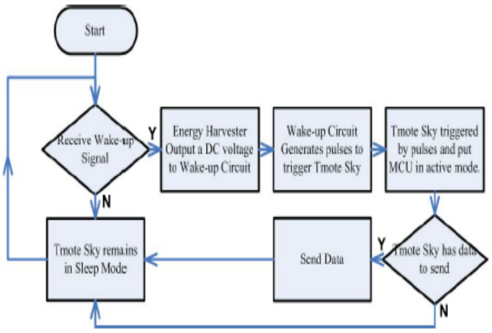

Fig 4 REACH Mote Flow chart

3.2 Comparison of the REACH-Mote and the WISP-Mote

Every mote designed can be used to achieve passive wake ups with different approaches. But the REACH mote and the WISP mote are more superior with some advantages namely:

• The WISP-Mote and EH-WISP Mote, because of MCU and radio either receiving or decoding hardware can achieve ID-based wake-up along with RFID reader when compared to the REACH mote as the wake-ups are eliminated when the sink is not interested in data from all sensor nodes.

• The flexibility in MAC protocol design can be improved due to the preprocessing of WISP's MCU.

• Most of the advantages of the WISP mote and EH mote are due to WISP's MCU. But because of this the energy consumption increases and hence REACH mote is preferred.
• REACH mote is more economical when compared to WISP mote.
•Due to the low energy consumption of REACH-Mote wake-up circuit ,it has an edge over WISP mote in wake-up range and wake-up delay.

4. Data Latency Optimization:

Sensor-MAC (S-MAC) [5] is considered as reference of MAC protocols that are designed for WSNs. It was the first work that managed the transceiver time between listening and sleeping modes in order to minimize the energy consumption during sleeping periods. Its main idea is to divide the transceiver time into two parts: active and passive. When the radio is in active mode, the sensor is ready to exchange data with its neighbors, and once it goes to passive state, it cannot transmit or receive data.The sender node must retry sending data, which will generate an energy loss. This problem is called deaf listening. To avoid this latter, S-MAC proposes synchronization between nodes using SYNC packet that is sent inthe beginning of the listening period. It can set up the both sleeping and listening modes, inall of the neighbor nodes. Figure 5shows the S-MAC protocol cycle organization, where $Ts$is the sleep period and $Fn$is the complete cycle of listen and sleep period that is called frame.

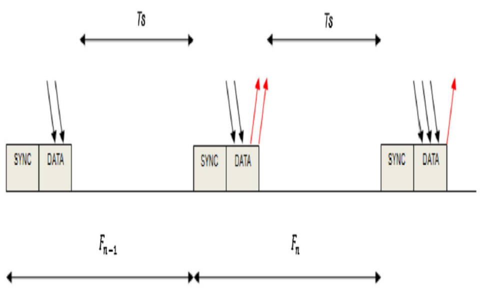

Fig 5 Duty cycle of S-MAC

The OOM-MAC Algorithm

In S-MAC protocol, the nodes are set to the passive/active mode periodically, the both parts of the cycle, are fixed previously, that presents the major drawback of this protocol. In our algorithm, we enhance the management of the sleep schedule. Note that, we keep the same basic features of the SAC protocol [6]; nodes follow the same synchronization rules of S-MAC protocol, the collision avoidance by RTS/CTS control messages, message passing and overhearing avoidance. Our algorithm is performed in two steps: The first step, is to do a sampling time in the interval $[0,Ts]$ (the interval depends on the duty cycle, for example, in our simulations we use a duty cycle of 10 %, and since the cycle frame period is 1.603s, the sleep period will be 1.442s. So, in this case we have to sample the interval $[0,\ 1.4s]$), and we calculate theprobability of transition from OFF to ON state for each sample, according to In the second step, we take a number, K, randomly in the interval [0, 1], and we compare it with the table of probability, calculated previously, if the number K is smaller than $Pi\ (ti)$,then the next activation moment of the transceiver is ti. Thus, the duration of the OFF state is $[0,\ ti]$, with a transition probability Pi . Once it is estimated the time activation of the next cycle, the node broadcasts its schedule to the neighbors by the SYNC packet.

5 Simulation Results

5.1 Simulation Parameters
The simulations are carried out using the simulator NS2(network simulator2), that is among of the most used simulators to study the performances of network protocols [7].At the application layer we used the ON/OFF Exponential traffic source that will show the effectiveness of OOM-MAC protocol.

To evaluate just theMAC layer, we use a static routing protocol that is the NOAH protocol [8]. 11 nodes with 10 hops are present in our Simulation topology generation. The first node,considered as the traffic source, and the last node is the sink. We consider that, just the neighbors of one hop are in the same area of scope. In other words, a node can exchange messages just with its immediate neighbors.

5.2 Measurement of Energy Consumption

When designing a MAC protocol for WSN we have to keep in mind that energy is an influencing factor which we have to consider, due to its low energy resources. Our objective is to reduce the latency without energy consumption using OOM-MAC protocol and demonstration of the difference between the energy consumption of OOM-MAC protocol and S-MAC one in simulation results clearly shows the effectiveness of OOM-MAC protocol.

To evaluate the energy performance, we calculate the energy consumed by all nodes on the network, for different traffic levels. During ON periods (burst time), the source node sends packets with an inter-arrival time that varies from 0.5s up to

5*s*. The horizontal axis indicates the inter arrival time of packet in the ON period, and the vertical axis shows the total of energy consumed at all nodes on the network for the transmission of 20 packet. The results of S-MAC protocol, twice higher, as compared to those given by OOM-MAC protocol because of the cycle of the OOM-MAC protocol is not constant, it is based on varying sleep schedule. In the OOM-MAC protocol, we estimate the period of sleeping state according to transition probability that based on ON/OFF Markov model. So, this makes the MAC layer more suitable for burst traffic load, thus, the transmission becomes twice as fast between the source node and destination, versus the S-MAC protocol.

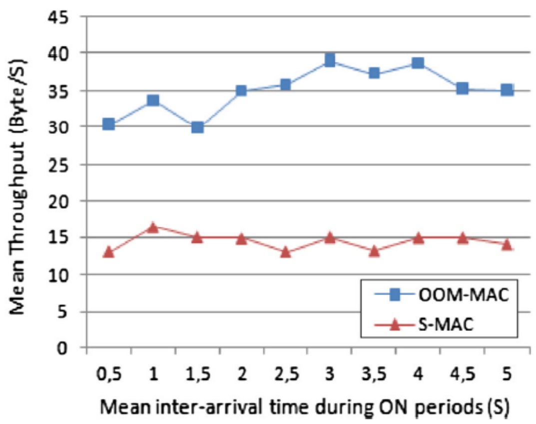

Fig. 6 Mean throughput in OOM-MAC and S-MAC protocol, with ON/OFF traffic source in high traffic load

Here we test and compare the performance of throughput in high traffic load by varying the number of nodes between the source and the destination, in the second we vary the inter-arrival time of packets, in a multi-hop network that includes 10 hops.

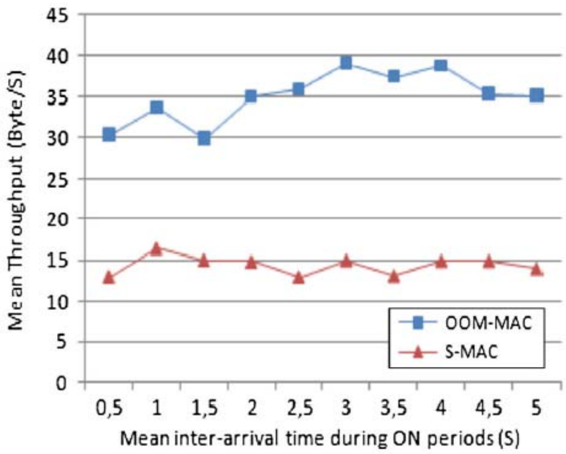

Fig. 7 Mean throughput in OOM-MAC and S-MAC protocol, with ON/OFF traffic source in different traffic load

Both Fig 6 and Fig 7 show the results of experiments between OOM-MAC protocol and S-MAC protocol. The OOM-MAC protocol results are more efficient compared to those obtained by S-MAC protocol in both cases.. We remark that there is a linear decrease versus the number of hops between source and destination node. That is because when we increase the number of hops in the network we risk to increase the traffic load and the congestion, which arise the collision problem .In Fig. 7, we note that there is a very important difference between the both curves, also we note that the OOM-MAC protocol preserves almost the same level of throughput in different traffic load levels.

These remarks show that the dynamic nature of the OOM-MAC protocol allows it to behave in correspondence with different traffic levels of the network.

6. CONCLUSION

In this paper, the concept of REACH-Mote has been discussed in order to increase the wake up range of passive wake up radio sensor nodes .When compared to other traditional WISP motes it clearly shows that REACH mote has 20% better coverage range. We also discussed about the data latency of OOM-MAC protocol using Markrov model and its simulation results generated using NS-2.

REFERENCES

1) H. Ba, I. Demirkol and W. Heinzelman, "Feasibility and Benefits of Passive RFID Wake-up Radios for Wireless Sensor Networks," IEEE Globecom, 2010.
2)http://www.ti.com/tool/msp430-3p-motei-tmotesky-dsgkt
3)Ye,W., Heidemann, J.,&Estrin,D. (2002).An energy-efficientmac protocol forwireless sensor networks.In: INFOCOM 2002. Twenty-first annual joint conference of the IEEE computer and communications societies. Proceedings. IEEE, Vol. 3, pp. 1567–1576.
4)Ye, W., Heidemann, J., &Estrin, D. (2004). Medium access control with coordinated adaptive sleepingfor wireless sensor networks. Networking, IEEE/ACM Transactions on, 12(3), 493–506. doi:10.1109/TNET.2004.828953.
5) Lin, P., Qiao, C., & Wang, X. (2004). Medium access control with a dynamic duty cycle for sensor networks. In Wireless communications and networking conference, 2004. WCNC. 2004 IEEE, Vol. 3, pp. 1534–1539
6) Li, Y., Ye, W., & Heidemann, J. (2005). Energy and latency control in low duty cycle mac protocols. In Wireless communications and networking conference, 2005 IEEE, Vol. 2, pp. 676–682
7)The network simulator - ns-2. http://www.isi.edu/nsnam/ns/.
8)NO ad-hoc routing agent (NOAH). http://icapeople.epfl.ch/widmer/uwb/ns-2/noah/.