A Solution to Energy Hole Problem In Wireless Sensor Networks Using WITRICITY

Mahendrababu.K, M.E.,Embedded system technologies, Sri SaiRam Engineering College, Chennai-44, India. mahendrababukothandan@gmail.com
Lakshmi Joshitha.K, Assistant Professor, Department Of ECE, Sri Sai Ram Engineering College, Chennai-44, India. Lakshmi.ece@sairam.edu.in

***Abstract*—One of the challenges faced by a Wireless Sensor Network (WSN) is the energy dissipation of the nodes that impacts lifetime of the node's battery. This is because the fact that nodes nearer to the sink carry heavier traffic loads than any other nodes. Therefore, the nodes around the sink would deplete their energy faster, leading to an energy hole around the sink. The aim of this paper is to overcome the power constraints in WSN by wirelessly charging the nodes through witricity (wireless electricity). It is shown that evanescent field patterns can be used to transfer energy efficiently over multiple hops. Here we introduce a new layer called the charging layer into the basic sensor network protocol stack. We analyse the energy depletion of nodes under flat and hierarchical routing schemes. The efficiency of a witricity system is also analysed.**

Keywords---wireless sensor networks, energy hole, witricity.

I.INTRODUCTION

Wireless sensor network is a group of spatially distributed and dedicated sensors employed for monitoring and recording the physical phenomena of the environment and thus organizing the collected data at a central location called base station or sink node. They can be used for surveillance in warehouses, factories, and companies. They can be used in the military to detect enemy infiltration and in the medical field to monitor patients' conditions. They can be also used to monitor environmental phenomena like volcanoes, earthquakes, or polar meltdown. The major limitation in WSNs is the Energy hole problem, which is a crucial issue in wireless sensor network. Nodes nearer to the sink region will die sooner from outer sub-regions because these nodes send their own data and also forward the data from outer sub-regions to the sink. So after very short time energy hole comes near the sink region.

After that, data cannot be transmitted to sink even though energy is still remained in outer region nodes which affects the lifetime of the network.

Today, a breakthrough called Witricity[2] allows us to wirelessly transfer energy between two nodes at midranges (1–3m). The energy transfer distance that witricity can achieve depends on various factors such as the radii of the coils and the number of turns. By reducing the radii of the coils and increasing the number of turns, the energy transfer distance can be increased. As the nodes in the network start to die, the coverage and connectivity in the network gradually diminishes and at one point of time the network fails. Experimental results in [3] show that up to 90% of the energy of the network can be left unused when the network lifetime is over if the nodes are uniformly distributed in the network. So, there will be a large number of functional nodes with no connectivity to the base station. Moreover, in some applications sensor nodes failure is not even acceptable.

II.CHARGING PROTOCOLS

In this section, we will examine multi-hop wireless energy transfer in WSN under two topologies: a flat topology and a clustered -topology. We first introduce the concept of charge coverage.

A.Charge Coverage

If energy can be delivered to the node, then the node is said to be charge covered. On the other hand if energy cannot be delivered to a node than the node is not charge covered. Once the network is deployed ,the efficiency of energy transfer will depend on main parameters; the distance between the nodes and the total number of hops of energy transfer.

B. Energy Transfer Schemes

We present three new techniques for multi-hop wireless energy transfer; the store and forward technique, the direct flow technique and the hybrid technique. As the names suggest the store and forward stores the energy at every hop whereas the direct flow does not and the hybrid is a combination of the two approaches. The store and forward technique assumes that each node is equipped with a rechargeable battery. The main power source will transfer energy to the nodes near to it. These nodes will store the energy by charging their batteries. Once their batteries are fully charged (or the source energy reaches a 50% threshold), the wireless energy transfer is terminated. Then, these nodes transfer the energy stored in their batteries to the next hop nodes which in turn store this energy in their batteries and in

ISSN: 2278-0181

the next round transmit it to the next hop nodes. Direct flow technique takes advantage of the fact that a single device can couple with multiple devices at the same time by receiving the energy directly from the previous node.

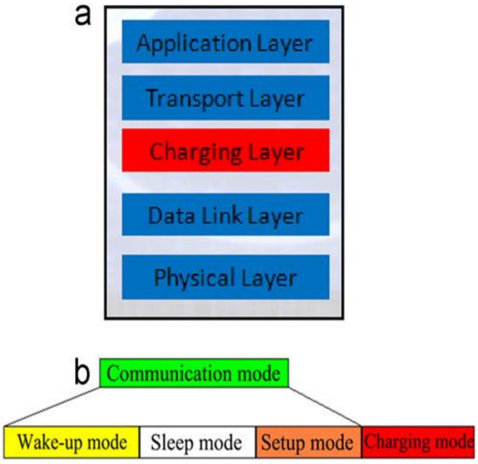

Fig.1.(a) The protocol stack in an immortal sensor node. (b) The operation modes of an immortal sensor node.

C. Flat Topology Charging Protocol(FTCP):

In this type of charging protocol, each node knows the distance to all its neighbours using any previously proposed localization algorithm. When a node's battery capacity goes below the threshold of 10%, the node needs to be charged and it switches to the setup mode. For a node to know how much energy is left in its battery, the hardware setup for recharge control is shown in section IV. The charging layer will send a RTC (Request To Charge). The message contains the ID of the node issuing the request. The RTC will then be flooded in the network. At every hop, the counter in the RTC is incremented and the node ID is appended to the RTC message. When a node receives the RTC message, it will test the counter; if this counter is above 8, the RTC message will be dropped. The node then checks which neighbour sent it the RTC message by testing the last ID of appended to RTC; if this neighbour is more than 1.5 m away, the message is dropped. Fig. 3 displays the different control packet formats sent and received by the charging layer. Fig. 2 shows the charging protocol in action.

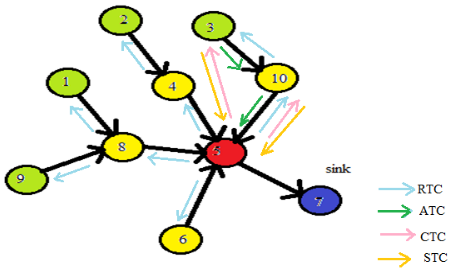

Fig.2. FTCP in action

Each node floods the RTC only once. So, if a node receives two RTC with the same node ID, it drops the second one. This greatly reduces the overhead of flooding and ensures a good efficiency.

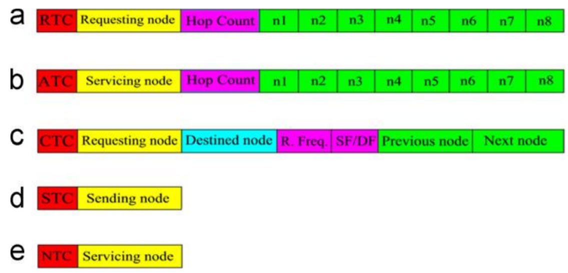

Fig.3.The different control packets sent and received by the charging layer for flat topology charging protocol. (a)Request to charge (b) Accept to charge message sent back (c) Confirm to charge message with resonant frequency specified in R. Freq. And the technique whether store and forward or direct flow being stored in SF/DF. The previous node, destination node, and next node are consecutive nodes on the energy path.(d) Start to charge message. (e)Not to charge message.

Once a RTC message reaches a node capable of charging the requesting node, it will send back an ATC (Accept To Charge). The ATC message will include the ID of this node, the number of hops, and the Ids of the nodes on the path.

The node then sends a CTC (Confirm To Charge) message to all the nodes on the energy route. The CTC message contains the ID of the requesting node, the ID of the intended node, the Ids of the two nodes consecutive to the intermediate node from which it will receive and send energy, the frequency of energy transfer, and a flag telling the node whether to store the energy in its battery or to directly transfer it to the next node.

When the nodes receive the CTC, they tune their capacitor to the specified frequency, send a STC (Start To Charge) message to the requesting node, and switch to the charging mode. The STC contains the ID of the node. When the requesting node receives the STC from all the nodes on the path, it sends a STC to the servicing node and switches to the charging mode. When the servicing node receives the STC message, it switches to the charging mode.

ISSN: 2278-0181

Once all nodes are in the charging mode, they couple together and the wireless energy transfer starts.

Once the battery of the charging node reaches a certain threshold (50%), it stops charging, switches to the wake-up mode and sends a NTC (No To Charge) message to all the nodes involved. When these nodes receive the message, they switch back to the wake-up mode.

D.Clustered Topology Charging Protocol:

After the network is divided into clusters whose cluster heads have the highest energy level, the nodes of the same cluster use a direct flow technique while the nodes belonging to different clusters use a hybrid energy transfer technique.

When a node needs to charge its battery it will send a RTC message to the cluster head. Since the cluster head is the node with the highest energy level, then it is the best choice among the one hop neighbours of the requesting node.

The cluster head sends an ATC to the requesting node. The requesting node sends the CH a CTC message containing its ID and the resonant frequency of energy transfer.

The CH tunes the capacitor to the specified frequency, sends a STC (Start To Charge) message to the requesting node (and the nodes on the path), and switches to the charging mode. When they receive the STC, they switch to the charging mode. The nodes then couple together and the direct flow wireless energy transfer starts.

Once the battery of the charging node reaches the threshold (50%), it stops charging, switches to the wake-up mode and sends a NTC (No More Charging) message to the other node. When requesting node receives the NTC message, it switches back to the wake-up mode.

III.WIRELESS POWER TRANSFER

In recent years, the strongly coupled energy transfer technique is based on magnetic resonance technology to achieve wireless power transmission. Transfer efficiency and transfer distance are two important indicators of wireless power transfer system. We can see that with the fixed system parameters and load conditions, the system efficiency η only depends on the coupling coefficient *K*. The larger the value of *K* is, the stronger the ability of system to carry the energy is. *K* and the mutual inductance *M* can be

$$K = \frac{\omega M}{2L}$$

$$M = \frac{\pi}{2}\frac{\mu_0 r_l^4 n}{D^3}$$

Where, *D* is the two coils centre distance, *n* is the number of turns for the coils. According to coupled model theory, the system inherent decay rate can be expressed as $\Gamma = r/2L$, quality factor $Q = \omega/2\Gamma$.

We can see coupling coefficient *k is* inversely proportional with the coil inductance *L*, proportional with the resonance frequency *f*, but reduce the inductance inherent of the system will increase the loss rate of Γ. Thus improve the system's natural frequency *f*, quality factor *Q*, reduce the system's inherent loss rate Γ is the key to improve the efficiency η.

If inside losses of two coils in the resonator are zero, the efficiency of resonator can reach 100%, it indicates that resonator only plays a role in energy transfer and does not consume energy. Now transfer efficiency η becomes

$$\eta = \frac{R_L \pi^4 f^2 \mu_0^2 r_l^8 n^2}{(R_L + r)\pi^4 f^2 \mu_0^2 r_l^8 n^2 + (R_L + r)^2 r D^6}$$

Where RL is the load resistance, *f* is the resonant frequency,µ is permeability of free space, r is the radius of the coil, D is the diameter of the coil, *n* is the number of turns.

IV.HARDWARE DESIGN

The hardware set up for wireless power transfer scheme is built around on a basic sensor mote, such as Berkeley's sensor mote with a coil, charging circuitry and a buffer capacitor usually a super capacitor to store energy with high density of charge. The charging control circuitry is composed of a micro controller to control energy transfer by comparing the residual voltage present in the batteries with help of reference voltages. Microcontroller takes care of routing control packets also the same processor used for sensor node is used for determining residual energy too. The switch used for charge control is a basic FET switch. The frequency of a.c output from inverter depends on switching frequency of FETs used in it.

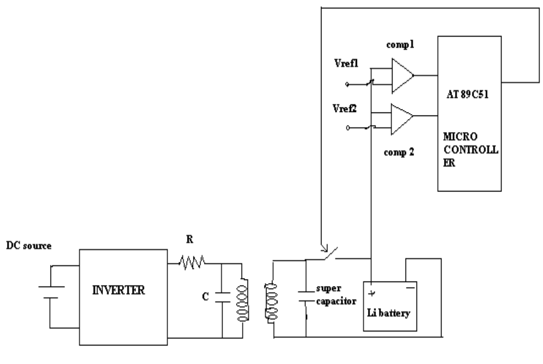

Fig.4. Charging control circuitry for wireless energy transfer.

ISSN: 2278-0181

V.SIMULATION RESULTS

In this section, we simulate the charging protocols using NS2 simulator. NS2 might not be the best tool to validate our theory however would help showing the effectiveness of our charging protocols in extending the network lifetime.

Real life experimentation is part of our current work. We compare the flat topology charging protocol (FTCP) with the clustered topology charging protocols (CTCP). We simulate the network energy depletion in both FTCP and CTCP with transmission of data packets. The following graph shows how energy of nodes depletes with respect to time.

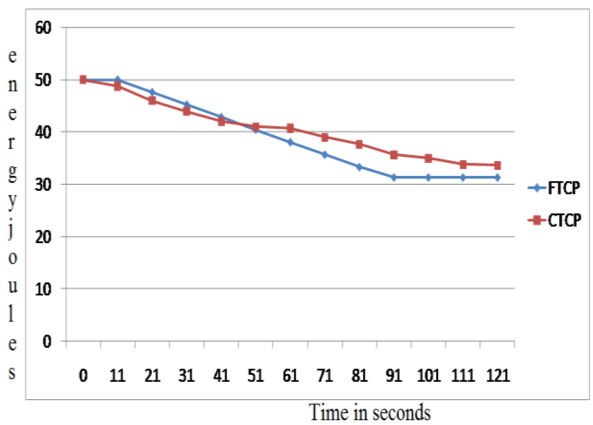

Fig.5. Energy depletion in FTCP and CTCP.

The efficiency plots by varying distance between two coils, number of turns and radii of the coils are plotted in MATLAB environment as follows:

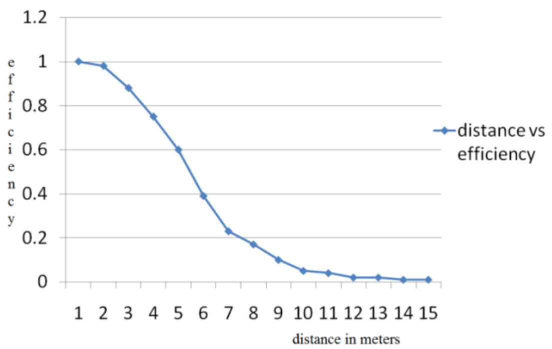

Fig.6. Distance Vs Efficiency

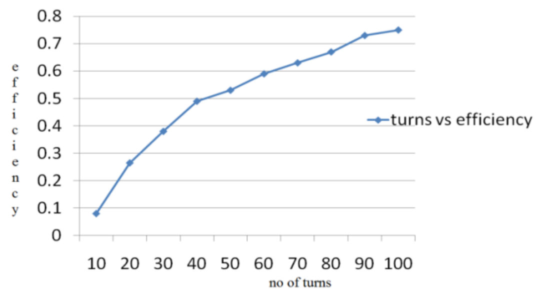

Fig.7. Number of turns Vs Efficiency

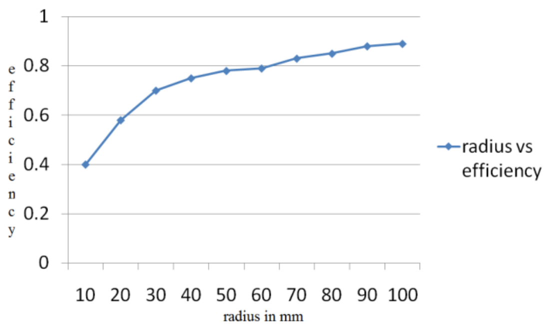

Fig.8. Radii Vs Efficiency

VI.CONCLUSION

We presented and analysed novel multi-hop wireless energy transfer protocols while keeping the efficiency of wireless energy transfer acceptable. Witricity is a new research topic as new ways to increase the efficiency of Witricity are developed; it will become easier to implement it in a WSN and the power constraint in WSN will no longer be a limitation.

VII. FUTURE WORK

Our future work is to develop hardware model to implement wireless energy transfer scheme between two nodes in real life scenario.

REFERENCES

[1] Mohamed K. Watfa, Haitham Al Hassanieh, and Samir Selman, "Multi-Hop Wireless Energy Transfer in WSNs,"IEEE Communications letters, Vol. 15, No. 12, pp. 1275-1277, Dec 2011.

[2] Karalis, J. D. Joannopoulos, and M. Soljacic, "Efficient wireless non radiative mid-range energy transfer," Annals of Physics, vol. 323, pp 34-48, Jan. 2008.

[3] Tan Linlin , Huang Xueliang , Li Hui ,Huang Hui, "Study of Wireless Power Transfer System Through Strongly Coupled Resonances," International Conference on Electrical and Control Engineering, pp 4275-4278, dec 2010.

[4] Morris Kesler "highly-resonant-power-transfer: Safe, Efficient, and over Distance," Witricity corporation, 2013, pp 1-31.

[5] Matt Perkins, Neiyer Correal, Bob O'Dea, "Emergent wireless sensor network limitations: A plea for advancement in core technologies," IEEE proceedings nov. 2002.