2008

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Recommended Citation

Watfa, Mohamed K.; Al-Hassanieh, Haitham; and Salmen, Samir: The road to immortal sensor nodes
2008.

<https://ro.uow.edu.au/dubaipapers/369>

The Road to Immortal Sensor Nodes

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Abstract— One major limitation in WSN is the lifetime of the node's battery. The aim of this paper is to overcome the power constraint in WSN by wirelessly charging the nodes using a newly discovered technique for single hop wireless energy transfer called Witricity. In this paper, we present new techniques for multi-hop wireless energy transfer. We specify the hardware a sensor node needs in order to wirelessly transmit and receive energy. Finally, we present a charging protocol for a WSN with flat topology and another for a WSN with clustered topology. Our results show that multi-hop wireless energy transfer can be done with an efficiency as high as 20% over 8 hops. The work in this paper is the first that addresses multihop wireless energy transfer in sensor networks and is the building block of our and other future research in this area.

Keywords—Witricity; multihop wireless energy transfer; sensor nodes.

I. INTRODUCTION

Sensor networks is a growing field in computer science. The technological advances in power electronics and radio transmission allow us to build small and inexpensive sensor nodes which together can form a wireless infrastructure less network. Dispersing the nodes in a certain area, allows us to accurately monitor the area. The nodes can sense a phenomenon or detect an event and send data to a base station. Sensor networks can be used in a variety of areas. 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 as well like volcanoes, earthquakes, or polar meltdown.

One of the main concerns in wireless sensor networks is energy constraints. A sensor node has a limited amount of energy stored in its battery and once this energy is consumed, the node dies. As the nodes in the network start to die, the coverage and connectivity in the network gradually diminish until the network fails. In most applications, like monitoring of volcanic areas, tropical rain forests, and polar ice caps, it is impractical to retrieve the nodes and replace their batteries. Moreover, in some applications sensor nodes failure is not acceptable. In medical and military applications, nodes failure might be fatal; resulting in the death of a patient or an enemy infiltration going unnoticed. Many papers have been published

that introduce new energy efficient protocols. However, all these protocols only extend the life of the network. However, today a breakthrough in technological development called Witricity [1] allows us to wirelessly transfer energy between nodes at mid ranges (1-3 meters). With this technology we can overcome the power constraint in WSN by constantly charging the nodes. In this paper, we use the concept of Witricity in WSN to efficiently charge the nodes paving the road to immortality. Integrating Witricity into WSN requires considering multi-hop wireless energy transfer since most nodes are several hops away from the base station. 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 doesn't and the hybrid is a combination of the two. For each of these techniques we derived the efficiency equation. The results for simulating these techniques show that energy can be transferred over 8 hops with an efficiency of 20% -for single hop the efficiency was 60% according to [2]. In order for a sensor node to transmit and receive energy, some hardware components must be added to the regular sensor node to make it an *Immortal sensor node*. The node requires a coil, capacitance, rechargeable battery, buffers and other component discussed in a later section. To handle the charging in the WSN, we introduce a new Charging layer between the network layer and the data-link layer. This layer is responsible for routing the energy in the network form a source node to the destination node while maintaining good efficiency energy transfer. This layer will implement the charging protocols for the flat network topology and the clustered network topology. The overhead of these algorithms is low and they allow the charging of all the nodes in the network while achieving good efficiency of energy transfer between the nodes. Thus our contribution in this paper is mainly two-folds. First, we present a strategy for multihop wireless energy transfer, comparing three different schemes through deriving their respective efficiency equations and deducing the optimal scheme. Second, we propose an efficient utilization of this strategy for the cases of flat and clustered topology through an intelligent communication protocol lying on top of the charging algorithm proposed.

The rest of the paper is organized as follows. Section II summarizes some related work. Section III introduces the multihop energy transfer analysis. Section IV provides the

hardware design details. Section V discusses the charging protocol. Simulation results are provided in Section VI. We conclude this paper in Section VII.

II. RELATED WORK

The bulk of our research is based on the concept of Witricity [1] which was recently discovered and allows us to wirelessly transfer energy between objects at mid ranges. The idea behind Witricity, presented in [1] and [2], is resonant electromagnetic coupling; two objects in resonance at the same frequency will tend to couple and energy will be transferred between them. Efficient energy transfer between the two objects requires strong coupling; i.e. the coupling coefficient κ must be larger than all the energy loss rates $\Gamma_{1,2}$.

The figure of merit for wireless energy transfer is

$$fom = \frac{\kappa}{\sqrt{\Gamma_1 \Gamma_2}} \quad (1)$$

Witricity is practically demonstrated in [2]. Energy is transferred between one coil capacitively coupled to a source and another coil capacitively coupled to a load at a resonant frequency ω . The experiment was performed in the presence and absence of a blocking wall between the two coils. The obvious limitations of their work was the distance by which the energy could be transferred and its resulting efficiency.

The equations for ω , κ and $\Gamma_{1,2}$ are given by:

$$\omega = \frac{1}{\sqrt{LC}} \quad (2)$$

$$\kappa = \frac{\omega M}{2\sqrt{L_1 L_2}} \quad (3)$$

$$\Gamma = \frac{1}{2L} \left[\sqrt{\frac{\mu_0 \omega}{2\sigma}} \frac{1}{4\pi a} + \sqrt{\frac{\mu_0}{\epsilon_0}} \left(\frac{\pi}{12} n^2 \left(\frac{\omega r}{c} \right)^4 + \frac{2}{3\pi^3} \left(\frac{\omega h}{c} \right)^2 \right) \right] \quad (4)$$

In the above equations, $L_{1,2}$ are the inductances of the coils, C is the capacitance, M is the mutual inductance between the coils, μ_0 is the permeability of free space, r is the radius of the coil, c is the speed of light, a is cross sectional radius of the wire, n is the number of turns, and h is the height of the coil.

The amplitudes of the magnetic fields at the source object and receiving device are respectively $|A_s|$ and $|A_d|$. If the load is consuming energy at a rate of Γ_{work} , the relation between the amplitudes of the fields becomes:

$$|A_d|^2 = |A_s|^2 \left(\frac{\kappa}{\Gamma_d + \Gamma_{work}} \right)^2 \quad (5)$$

[1] and [2] show that the efficiency of wireless energy transfer is given by:

$$\begin{aligned} \eta_{work} &= \frac{\Gamma_{work} |A_d|^2}{\Gamma_s |A_s|^2 + \Gamma_d |A_d|^2 + \Gamma_{work} |A_d|^2} \\ &= \frac{1}{\frac{\Gamma_d}{\Gamma_{work}} \left[1 + \frac{1}{fom^2} \left(1 + \frac{\Gamma_{work}}{\Gamma_d} \right)^2 \right] + 1} \end{aligned} \quad (6)$$

It is clear from this equation that as fom increases, the efficiency of energy transfer increases.

Once we incorporate Witricity into WSN, we will examine two types of network topologies; a flat topology and a clustered topology. Energy efficient clustering algorithms are presented in [3], [4], and [5]. The most important of which is LEACH (Low Energy Adaptive Clustering Hierarchy) protocol [5]. LEACH divides the network operation into rounds. During each round, clusters are formed with new cluster-heads. Rotating the cluster-heads allows balancing the energy between the nodes and increases the network lifetime. The concept of clustering will aid us to design an efficient protocol that utilizes the idea of energy transfer to balance the energy between a fully charged node and a node that is in need of energy.

III. MULTIHOP WIRELESS ENERGY TRANSFER

Single-hop wireless energy transfer was presented in [1] and [2]. In this paper, we will present three new techniques for multi-hop wireless energy transfer and derive the efficiency of energy transfer in each of these techniques. The aim is to transmit energy from a base station or a source node to a node N hops away.

A. Store and Forward Technique

In this technique, each node on the path from the source to the destination node receives the energy and stores it in its battery. It then forwards the energy to the next node on the path. At every hop, two nodes couple together independent of other nodes in the network. Starting from equations (5) and (6), we can derive the efficiency of store and forward multi-hop wireless energy transfer over N hops. We showed that the efficiency over N hops is just the product of efficiencies at every hop. This is highly intuitive since the energy transfer at each hop takes place at a different time and independently of the other hops. The efficiency is given by:

$$\eta = \prod_{i=1}^N \left(\frac{1}{\frac{\Gamma_{n[i]} + \Gamma_{ch\arg-loss[i]}}{\Gamma_{ch\arg-ing[i]}} \left[1 + \frac{1}{fom_{[i]}^2} \left(1 + \frac{\Gamma_{ch\arg-ing[i]}}{\Gamma_{n[i]} + \Gamma_{ch\arg-loss[i]}} \right)^2 \right] + 1} \right) \quad (7)$$

$\Gamma_{\text{charg-loss}[i]}$ is the rate of energy lost due to charging at node i , $\Gamma_{\text{charg-ing}[i]}$ is the rate of energy consumed by charging the battery at node i , and $\Gamma_{n[i]}$ is the energy loss rate at node i . In order to analyze the efficiency, we simplified this equation by assuming that the nodes are identical. This is a reasonable assumption since the nodes can be manufactured with the same parameters and thus the loss rates will approximately be the same. We will also incorporate the values of $\Gamma_{\text{charg-loss}[i]}$ into Γ_n . The simplified equation becomes equation (6) to the power N :

$$\eta = \left(\frac{1}{\frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} \left[1 + \frac{1}{fom^2} \left(1 + \frac{\Gamma_{\text{charg-ing}}}{\Gamma_n} \right)^2 \right] + 1} \right)^N \quad (8)$$

B. Direct Flow Technique

This technique takes advantage of the fact that a single device can couple with multiple devices at the same time. In this technique, each node couples with previous and following nodes on the path from the source node to the destination node. Once this node receives the energy from the previous node, it directly transmits it to the following node without storing it in its battery. We don't have charging and discharging losses except at the last node. In this technique, we assume that the loss rates at the intermediate nodes will not be doubled. In the store and forward technique, Γ_n of the intermediate nodes is considered twice; once while receiving energy and once while transmitting energy. In this case, the energy is being received and transmitted simultaneously, and thus Γ_n should be considered only once.

We also make the assumption that equation (5) is still valid with Γ_{work} being replaced by the summation of energy loss rate at subsequent nodes since the energy lost at a node is being used at later nodes. The figure of merit in this case is the geometric mean of all the coupling coefficients over the geometric mean of all the loss rates. It is given by:

$$fom = \frac{\sqrt[N]{\prod_{j=1}^N \kappa_{[j]}}}{\sqrt[N+1]{\Gamma_{n[0]} \prod_{j=1}^N \Gamma_{n[j]}}} \quad (9)$$

In this case the efficiency is more complex and it is given by:

$$\eta = \left(\frac{\frac{\Gamma_{n[0]}}{\Gamma_{\text{charg-ing}}} \prod_{j=1}^N \left(\Gamma_{n[j]} + \Gamma_{\text{charg-ing}} + \sum_{m=j+1}^N \Gamma_{n[m]} \right)^2}{fom^{2N} \left(\Gamma_{n[0]} \prod_{j=1}^N \Gamma_{n[j]} \right)^{\frac{N}{N+1}}} + \frac{\Gamma_{n[N]}}{\Gamma_{\text{charg-ing}}} + 1 \right)^{-1} \quad (10)$$

$$+ \sum_{i=1}^{N-1} \left[\frac{\Gamma_{n[i]}}{\Gamma_{\text{charg-ing}}} \prod_{j=1}^i (\kappa_{[j]})^2 \frac{\prod_{j=i+1}^N \left(\Gamma_{n[j]} + \Gamma_{\text{charg-ing}} + \sum_{m=j+1}^N \Gamma_{n[m]} \right)^2}{fom^{2N} \left(\Gamma_{n[0]} \prod_{j=1}^N \Gamma_{n[j]} \right)^{\frac{N}{N+1}}} \right]$$

Again, we simplified this equation by assuming that the nodes are identical. The resulting efficiency equation becomes:

$$\eta = \left(\frac{\frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} \frac{1}{fom^{2N}} \prod_{j=1}^N \left(j + \frac{\Gamma_{\text{charg-ing}}}{\Gamma_n} \right)^2}{+ \frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} \sum_{i=1}^{N-1} \left[\frac{1}{fom^{2(N-i)}} \prod_{j=i+1}^N \left(j + \frac{\Gamma_{\text{charg-ing}}}{\Gamma_n} \right)^2 \right] + \frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} + 1} \right)^{-1} \quad (11)$$

One important thing to notice about this equation is that as the figure of merit increases, the efficiency will always increase.

C. Hybrid Technique

The hybrid technique uses a combination of both the store and forward technique and the virtual circuit technique. In this technique, energy is transferred using the direct flow technique for a small number of hops M and then it is stored at the M^{th} node. It is then forwarded to the next M^{th} node again using direct flow technique. So if we want to transfer energy over N hops. We can divide the energy transfer over k direct flow transmissions, each of M hops with $N=k*M$. The figure of merit is given by (9) with N being replaced by M . The efficiency of the energy transfer will be the product of the efficiencies of the k direct flow transmissions. For simplicity, we will present the efficiency of the hybrid technique for the case where all the nodes are identical. Thus, for energy transmission over N hops with M hops direct flow transmission, the efficiency is given by:

$$\eta = \left(\frac{\frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} \frac{1}{fom^{2M}} \prod_{j=1}^M \left(j + \frac{\Gamma_{\text{charg-ing}}}{\Gamma_n} \right)^2}{+ \frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} \sum_{i=1}^{M-1} \left[\frac{1}{fom^{2(M-i)}} \prod_{j=i+1}^M \left(j + \frac{\Gamma_{\text{charg-ing}}}{\Gamma_n} \right)^2 \right] + \frac{\Gamma_n}{\Gamma_{\text{charg-ing}}} + 1} \right)^{-1} \quad (12)$$

For $M=N$, the hybrid technique is identical to the direct flow technique. For $M=1$, the hybrid technique is identical to the store and forward technique. The question remains as how to choose the value of M . We will show in section 6 that for every value of N , there is a choice of M that will result in maximizing the efficiency of energy transfer. There is no closed form solution for this value, but we can find it numerically.

IV. HARDWARE OF THE IMMORTAL SENSOR NODE

Each sensor node will be formed of a basic node and additional hardware for wireless energy transfer. The sensor node must have a coil capacitively coupled to a rechargeable battery. The rechargeable battery will act as load when the battery is being charged by the coil and as a source when the battery is discharging in the coil. Since multiple nodes might be transferring energy at the same time, they must use different resonant frequencies as not to interfere with each other. Thus each node will have a specific resonant frequency which it will use to get charged. The charging nodes will have to tune there capacitors to get the same resonant frequency using equation (2). The actual building of the immortal sensor node is the subject of further research. However, we present here a preliminary model of the immortal sensor node shown in Figure 1.

Figure 1. The hardware model of an immortal sensor node

V. CHARGING PROTOCOL

We will examine multi-hop wireless energy transfer in WSN under two topologies; a flat topology and a clustered topology. We will suggest a protocol for each topology. However before going into the protocol, a question is raised as to whether we can charge every node in the network. Thus we introduce the concept of 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 then 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. If the total number of hops is larger than 8, the efficiency becomes significantly low. Moreover, from equation (3) increasing the distance between the nodes drastically reduces the coupling coefficient and consequently the efficiency. Therefore, we will define a node a charge covered if it satisfies the following two conditions.

- 1- The node has at least one neighbor who is at a distance not greater than 1.5m.
- 2- There is a node capable of charging this node that is no more than 8 hops away.

The choice of 1.5m and 8 hops is partially arbitrary. One can choose smaller values as 1.3m and 6hops. However, one cannot choose higher values such as 2m and 10 hops since the energy transfer in that case will be totally inefficient. Requiring the nodes to be at least 1.5m away from each other implies that the network must be dense. Ensuring that the network is charge covered will be the topic of a later research. In this paper, we will assume that all the nodes are charge covered.

A. Charging Algorithm for a Flat Topology

In case of flat topology, all nodes are at the same hierarchy. When a node's battery capacity goes below the threshold of 10%, the node needs to be charged and it switches to the charging mode. In the charging mode, the node stops sending and receiving data packets and starts sending charging control packets. The node will send a RTC (Request to charge message). The message contains the ID of the node issuing the request –the ID can be IP address or MAC address- and a counter as shown in Fig. 2. The node issuing the request will send the RTC to all its neighbors. 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. In order to reduce the overhead of flooding, each node floods a specific RTC only once and it does not send the packet back to the neighbor from which the packet arrived. Once an RTC message reaches a node capable of charging the requesting node, it will send back an ATC (Accept to charge). This node will be called the servicing node. The ATC message will include the ID of this node, the number of hops, and the IDs of the nodes on the path. When a node receives the first ATC message, it waits for 30sec; if another ATC message arrives the node chooses the one with the least number of hops. We will show in the following section that the optimal technique to use for total number of hops 2-6 is the direct flow technique. For the total number of hops 7-8, the optimal technique is a Hybrid with M=4.

Figure 2. The different control packets for flat topology charging protocol. All packets start with the type and the ID of the node sending the message. (a) Request to charge message (b) Accept to charge message (c) Confirm to charge message (d) Start to charge message (e) No to charge message

The node then sends a CTC (Confirm to charge) messages 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 tell the node whether to store the energy in its battery or to directly transfer it to the next node as shown in Fig. 10. When the nodes receive the CTC, they tune their capacitor to the specified frequency, switch to charging mode, and send a STC (Start to charge) message which contains the ID of the node to the requesting node. When the requesting node receives the STC from all the nodes, they couple together and the wireless energy transfer starts. Once the battery of the charging node reaches a certain threshold (60%), it stops charging and sends a NTC (No to charge) message to all the nodes involved. The nodes then switch back to regular mode of operation. If a node is near to the base station, the node can always charge from the base station using the same protocol. The only difference in this case is that the node sends the RTC directly to the base station.

B. Charging Protocol for Clustered Topology.

In this protocol, the network is divided into clusters using one of the algorithms in [3], [4], or [5]. We assume that the nodes in the same cluster know the distance between each other. The idea is for the nodes of the same cluster to use a direct flow technique and outside the cluster to use hybrid technique. When a node needs to charge its battery it will send a RTC message to the cluster head. If the cluster head is able to charge the node it does; else it sends the RTC to all the nodes in the cluster as shown in Fig. 16a. The nodes capable of servicing the request will send an ATC (Accept to charge) message. The ATC will contain the ID of the node servicing the request and the distance between the servicing node and the requesting node.

At the cluster head, if there are some ATC messages with distances no more than 1.5m, all the messages having distances greater than 1.5m are dropped. Then the node which is closest to the requesting node is chosen to service the request. The cluster head sends an ATC to the requesting node containing the ID of the servicing node and type 1 which means that the energy transfer will be over 1 hop as shown in Fig. 3b. The requesting node sends the servicing node a CTC message containing its ID and the resonant frequency of energy transfer. When the servicing node receives the CTC, it tunes the capacitor to the specified frequency, sends a STC (Start to charge) message to the requesting node, and switches to the charging mode (Fig. 3c). When the requesting node receives the STC, it switches to the charging mode. The nodes then couple together and the wireless energy transfer starts as shown in Fig. 3d. 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. In case at the cluster head there were no messages received with distance less than 1.5m. Then the cluster head chooses the node that is nearest to it. In this case the energy transfer will take place over two hops through the cluster head using the direct flow technique. The cluster head sends an ATC containing the ID

of the servicing node and type 2 which means that the energy transfer will be over two hops; i.e. through the cluster head as shown in Fig. 3b. Following the same steps as before, the requesting node sends a CTC message and when the servicing node and the cluster head reply with the STC message, the node gets charged; Fig 3c. In case there are no nodes in the cluster that are able to service the request, the cluster head charges itself first and then charges the requesting node (Store and Forward). The cluster head uses the algorithm presented for the flat network to charge itself. The difference is that cluster head sends the RTC to the other cluster heads and not all the nodes in the network. Once the cluster head is charged, it can transfer energy to the requesting node.

Figure 3. The charging protocol for the clustered topology showing two cases (a) Requesting node sends RTC to cluster head which forwards RTC to all other nodes in the cluster. (b) Servicing node sends ATC to cluster head which sends it to the requesting node. (c) Requesting node sends CTC to involved node. The involved nodes reply by a STC. (d) Energy is transferred through the cluster head in the first case and directly in the second case.

VI. SIMULATION RESULTS

To be able to simulate the efficiency of the 3 charging techniques, we first extend the equation (3) of the coupling coefficient between two coils:

$$\kappa = \frac{\omega M}{2\sqrt{L_1 L_2}} = \frac{\omega \frac{\pi}{2} \mu_0 n_1 n_2 \frac{(r_1 r_2)^2}{D^3}}{2\sqrt{\mu_0^2 n_1 n_2 r_1 r_2 \left(\ln\left(\frac{8r_1}{a_2}\right) - 2 \right) \left(\ln\left(\frac{8r_2}{a_2}\right) - 2 \right)}} \quad (13)$$

Figure 4. The efficiency of the multi-hop wireless energy transfer verses the total number of hops N. The plots correspond to the store and forward technique, the direct flow technique, and the hybrid technique for values of M=2, 4, & 6. The efficiencies are calculated for nodes with coils of 4cm radii.

Figure 5. The efficiency of the hybrid multi-hop wireless energy transfer verses the total number of hops N and the number direct flow hops M.

In this equation, D is the distance between the coils, $r_{1,2}$ are the radii of the coils, and $n_{1,2}$ are the number of turns of each coils. It is clear here that increasing the radii of the coils and the number of turns increases the coupling coefficient. On the other hand, increasing the distance between the coils reduces the coupling coefficient. The coupling coefficient is directly proportional to the figure of merit and the efficiency follows the figure of merit. In [2], the experiment is performed for coils with radii of 25cm each. Unfortunately, in a WSN, we do not have the luxury of using large coils. For the values presented in this section we chose the value of the radii of the coils to be 4cm and the distance between the coils to be 1m. Using equations (4) and (13), we find the values of the loss rates and the coupling coefficient and then use a Matlab code to calculate the efficiency in equations (8), (11), and (12) for

different values of N . The efficiency of energy transfer verses the total number of hops is plotted in Fig. 4.

The plot of Fig. 5 shows that the direct flow technique performs better than the store and forward technique for all number of hops. The store and forward technique reaches 10% at $N=5$ hops whereas the direct flow technique reaches 10% at 8 hops. The performance of the Hybrid technique depends on the choice of M . For large number of total hops N , the hybrid technique seems to always perform better than the other two techniques. For small values of N , the hybrid technique performs better than the store and forward but not better than the direct flow technique. The efficiency of the wireless energy transfer verses the total number of hops N and the number direct flow hops M is plotted in Fig. 4. This graph shows that for each value of N , there is an optimal value of M that gives the highest efficiency. For $N=7$, the optimal is $M=4$; for $N=10$, the optimal is $M=5$; for $N=13$, the optimal is $M=5$. Moreover, for each value of N , the efficiency of energy transfer with respect to M is a concave function. Thus, the optimal value of M is in the middle range 4-6. For high and low values of M the efficiency drops. At high values of N (>16), one can see that for M in the range 4-6, the hybrid technique is still able to maintain an efficiency over 2%.

VII. CONCLUSIONS AND FUTURE WORK

In short, multi-hop wireless energy transfer is implementable while keeping the efficiency of wireless energy transfer acceptable. Thus, we can use multi-hop wireless energy transfer in a WSN to charge the nodes and increase the efficiency of energy transfer. The Charging protocol that will be used to charge the nodes will also increase the efficiency and allow all nodes in the network to be charged. 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 be overcome. Our current research includes developing and testing real nodes with the capability to send and receive energy and testing our speculations and theoretical analysis presented in this paper. Also, extensive simulation results are being developed and the algorithms are being refined and would be included in an extended version of this paper.

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