A Protocol Development for Wireless Power Transfer over ad hoc networks

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***Abstract*—Since wireless power transfer is employed in many fields of application, specific situations in ad hoc environments are considered as a base for preparing an energy-oriented network protocol in order to deploy energy services. Initially are described some historic events, the components of the system, some implementations and similar technologies. Later, several ideas about energetic resources, electric power systems, management and energy transmission scenarios are discussed. Finally some relevant issues in related areas are explained as a future work.**

Keywords—Wireless power transfer; energy harvesting, ad hoc networks; altruistic behavior; far field; PoWiFi; energy-oriented networking protocol; witricity.

I. INTRODUCTION

There is a growing volume of research related to the wireless transmission of energy and information, mainly focused on the development of technologies, devices and services with an emphasis in commercial applications as consumer, industrial and military [1]. In many cases, wireless technologies and ad hoc networks are strong related.

Ad hoc networks are characterized for not requiring necessarily a physical fixed infrastructure. On the contrary, they are constantly changing. This dynamic character is possible thanks to an effective connectivity between the nodes that support the network and the availability of a source of energy in each of them. Frequently the mobility of the nodes brings new problems, because increases interactions complexity in the network.

As energy is a fundamental variable in the operation of any telecomunication network, adopting techniques of optimization becomes essential. With this design constraint, different protocols have been developed for energy management in ad hoc networks from particular premises of efficiency, availability, mobility and performance.

In this paper a behavior-based strategy that allows to delivers energy to a privileged node in an ad hoc network is presented. The strategy determines the character of a particular energy-oriented protocol that provides energy to a critical node even in the expense of the availability of other nodes in the network in order to guarantee its extended operation.

The protocol development basis shown in this paper will serve as a sharing and distribution mechanism of energetic services in the frame of Wireless Local Area Networks (WLAN). The group of standards IEEE 802.11 was chosen given its popularity, the volume of information, availability of libraries in simulators, the accesibililty of unlicensed frequency bands and the low cost of equipment. The evaluation of this protocol will be carried out by means of simulations which are set out in the chapter dedicated to future work.

In the present document the terms energy and power are interchangeably used, although of their physical meaning is theorethically well differentiated. Also it is considered that the communication links are tipically established in the far field zone.

II. HISTORICAL EVENTS

Below is a brief look at the evolution of energy transmission wirelessly through relevant milestones, some concerned with telecommunications:

- "This energy will be collected all over the globe preferably in small amounts, (…). One of its chief uses will be illumination of isolated homes". Nikola Tesla 1899 [2]
- Terrestrial transmission of 30KW to a mile, 2.388 GHz. 1975 [3]
- Transmission of 10KW to an airplane at 150m, Industrial Scientific and Medical (ISM) Bands. 1988 [3]
- Wireless charge of a portable phone 2.45 GHz [4]
- 60 W transmission to 2m, 9.9 MHz. 2007 [5].
- Wi-fi energy and data transmission, 8.5m. [6].

III. RELATED WORK

In general the strategies to make good use of energy in telecommunications networks are varied, going from optimization in nodes for improving energy efficiency until the development of diverse techniques for transmission and routing to reduce overall system power.

Considering initially the physical level, the antenna systems typically used to fulfil energy harvesting are known as rectennas, [7]. Which realize an early rectification of signal to capture energy from the wireless medium; often the content of information is not completely usable.

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New developments in antenna arrays designed for energy harvesting [9], make possible the improvement of the overall energy efficiency and offer high flexibility in the establishment of network topologies, this at the cost of a greater complexity in transmission, reception and control systems also as the routing protocols.

In the area of radio cognitive it has been expanded the possibilities of radio spectrum management; e.g. IEEE 802.11h protocol provides management of power and frequency dynamically in order to find the best power levels and appropriate channels to transmit. The final result on the Wi-fi throughput is near to the optimal performance of a network in infrastructure mode [10].

Similarly in the field of sensors networks, multiple approaches for energy transmission management are used; some based on traditional power saving mechanisms through handshaking techniques in Transfer Control Protocol TCP [11] others by means of creative procedures as suggested by [12] where a mobile device delivers periodically the energy in every sensor, through an optimal route. In any case the application of optimization techniques is required, because there is a compromise between throughput performance and the power transmission. In [13] is done an analysis about routing strategies for power transmission, based on time multiplexing.

In this regard and starting from the principle formulated by Shannon that indicates that "probability of error could be made nearly zero for all communication rates below channel capacity" [14]; it would exist at least one combination of parameters such as coding, modulation, etc., that allow to deliver a certain amount of energy to a remote node, while it is maintained an acceptable communication link [15].

As to the approaches orientated to behaviors in ad hoc networks, it is considered that it ocurrs an improvement in the energy efficiency of ad hoc networks when management is based on an altruistic behavior [16], which gives priority to the general network interest over the particular interest of the individual nodes.

IV. RELATED DEPLOYMENTS

In [6] it is reported an energy and information transmission of several consumer devices (a router, a camera, temperature sensor and battery chargers) by means of WLAN up to a distance of eight meters, by means of modifying the handshaking TCP in wireless routers, for maintaining a communication link while each of these devices are fed through various IEEE 802.11 channels. In this article are described the hardware, the evaluation of the resultant traffic and the simulations that finally led to the development. Likewise it introduces the PoWiFi term, to describe the energy-information dual connection.

Additionally from Google Patents a limited number of publications on ad hoc networks are chosen. These are related with topics of wireless energetic managing. Some of them describe alternative and / or complementary mechanisms to IEEE 802.11 methods and are of interest to gain a general understanding of this kind of methods. Here they are in technical complexity order though not chronologically.

A. PATENTS OF REFERENCE

In 2012 a patent for Energy Harvesting [17] to a electronic system for power transmission between mobile devices, was granted. It works in the range of micro- and milliwatts for both Global System for Mobile (GSM 980 MHz) and Wi-Fi (2.4 GHz). The energy received in the remote device is proportional to the size of a file and/or to the sending duration. Another complementary way for gathering energy is simply to tune a frequency and to transfer the residual energy after passing trough the receipt and energy conversion stages, for finally be stored in a local battery. In [18] a similar WLAN system it is described in a detailed way, here the remote node does not use a battery for enery storage but a capacitor.

In [19] is described a semi-broadcast system and methods to communicate at least three agents without hierarchical organization. This work presents techniques to avoid some typical problems associated to the wireless networks as the retransfers due to hidden terminal and the inequitable access in WLAN.

In [20] are detailed some techniques to manage power and frequencies in a wireless access protocol, nodes are activated only when a communication is required by sending wake-up messages. Optimization power/performance set points are provided. The methods used for synchronizing the nodes and the sequences of the different frequencies available in a dinamically and reconfigurable network are described. In this development, a master node is responsible for managing synchronization, the other nodes can be eventually promoted to a master node.

In [21] is defined a management hierarchy concept, based on categorize the nodes with a tier identification number, to allow implementing power saving techniques like wake up-sleep synchronized periods. In [22], synchronization is established by hops, through the exchange of information with neighboring nodes. It requires at least one node that generates the time base, the hop count is updated periodically on all nodes so that the information about the network topology is distributed. Although is not done explicit reference to the power management, this deployment it is interesting cause the neighborhood of each node is known; and in a power transmission protocol, these nodes have priority. Also allows the use of nodes with time references based on Global Positioning System (GPS).

In [23] is proposed the use of a particular node as a cluster-head or master node to manage idle and active nodes on different RF channels. The above in order to manage links for control trafic which permits to idle nodes to conserve their battery resources, on the other hand the active nodes are sent to data traffic channels. The cluster-head also coordinate scheduling activities for nodes; each node has to report with him, an idle node that is required becomes an active node. This structure it generates a hierarchical differentiation between cluster-head, active and idle nodes. Synchronization is done by Time Division Multiplexing (TDM) and the cluster-head manages the processes related with routing and managing energy network.

In [24] is described a hybrid system of ad hoc nodes, an infrastructure equipment and a distributed software that manages the overall system described; here there is a spatial locating functionality that permits provide energy directly to a specific node through a directive beam of energy. Similarly in Similarly in [26] the methods presented includes 3D adjustable directivity by means of RF techniques as contructive interference patterns, simultaneous transmission in different channels in Wi-Fi, Bluetooth, infrared; from a radio base and a protocol for transmiting energy to devices such as portable computers, cell phones or tablets.

A consumer variation of this system is described in [25] with the characteristic that is a laptop who acts as a wireless access point and delivers energy to different wireless PC peripherals, in various wireless communications standards, here the devices are connected in infrastructure mode.

Finally, in [27] are described several methods for controlling power transmission in Wi-Fi nodes via RF techniques as: to increase duty cycle, to decrease path loss, to adjust timing parameters, to choose the frequencies, to use radio cognitive techniques, to maintain RF routing tables with information about energy capabilities of the nodes, etc.

V. ENERGY AND INFORMATION NETWORKS

Conceptually power transmission wirelessly can be compared with the Power Line Communications (PLC) technology, which provides telecommunications services through the supply lines of electricity. In both, users receive energy services and telecommunications.

There are also technologies like Smart Grid (SG) which differs mainly by its area of use, since in SG transport and/or distribution infrastructure, and/or wide area telecommunications networks are used for energy management purposes; while PLC technology has a local area application. Typically smaller is oriented toward an infrastructure network or end-user access.

Complementary to wireless power transfer and PLC, are available other wireless technologies like the Visual Line Communications technology (VLC), which is oriented to data transmission through the office or home lights and the Free Space Optical Communications technology (FSO), which typically transmit information using coherent light beams.

From the standpoint of telecommunications, currently these technologies compose infrastructure fixed networks and usually converge on the end-user environment; in some cases converge also in access, transport or routing protocols. There are several technologies that rely on this physical infrastructure such as: Home Automation, Wireless Access Technologies, Internet of Things (IoT), etc.

Specifically in the field of wireless power transmission there are some popular terms such as Wireless Power Transfer (WPT), Energy Harvesting, Wireless Charging, or Witricity; as has been stated in this document before. These terms are generally refered to the ability to send power wirelessly through electrodynamic fields and radiofrequency techniques. These technologies make use of many developments made from the times of the classical electromagnetic theory, which have been firmly established since the beginning of the previous century; so there are few recent novelties that have been made to the foundaments of this field and that have to do directly with the applications presented here.

Since there is not exist a formal name for these technologies, for purposes of this document, has been given a prevalence to the Wireless Power Transfer term, because is the one that we consider it best fits, so much in the context of ad hoc network protocols as in the energy services in a telecommunications network. It is noteworthy that will be covered only telecommunications technologies in the far field radiation emitters, as was said before, i.e. long reach when compared with the wavelength of transmission.

Moreover, currently commercial wireless communications networks, do not consider the purpose of energy transmission directly but as the necessary means to transport information. However as it has explained before, are frequently used various techniques of management and optimization of resources in the network nodes, in the access level or in the routing strategies, which are of great interest for the design of an energy-oriented protocol.

VI. RESOURCES AND SERVICES MANAGEMENT

If the energy is understood as a resource, then it is predisposed of being managed as a service in a network and can be eventually controlled, delivered, received or negotiated. In this sense, as the nodes of the ad hoc networks tipically have at least a radio receiver and a radio transmitter, the natural medium of exchange is the wireless link.

Taking advantage of advanced features in some ad hoc networks, capables to adapt the parameters of transmission in some of its nodes, it is possible to mitigate the energetic constraints of the network by means of the formulation of specific strategies of connection, routing and energetic management, in order to extend in the time the availability of the network, of a node or of a particular service.

Bearing in mind that already exist analogous systemsdedicated to the transmission of the energy, specifically the distribution systems of the traditional electric power; which have developed during decades and have mature and well established management techniques, it is a good exercise to check and to consider the applicable concepts, normally used in these networks to do functional comparisons, to extract some definitions and get useful conclusions, in order to prepare an energy-oriented communication protocol and also to make appropiate simulations in ad hoc networks context. It is important to mention that the following information does not fit necessarily to the state of art in the field of electrical utilities and management systems.

It can be observed that for effects of energy transmission of across wireless means, it is possible to relate and to share (saved proportions), some common characteristics. In view of the same origins based on the electromagnetic fundamental theory, it is known that exist analogous topics in the transmission of energy in electrical conductors and in the dielectric energy transmission means (WLAN).

For example, there are similarities between conversion processes AC/DC (Alternative Current - Direct Current) taking place at some stage of distribution system in traditional electrical systems and also in the energy harvesting processes when an RF signal is finally converted in a DC level in a local battery or capacitor, the energy travels in the transmission media in a carrier before being finally used. Likewise is correspondent the separation of power flows phenomena in distribution lines, that is known in wireless communications as the diversity of RF paths, an event usually associated with interference and concepts as the Fresnel zones in radio communications.

Another key aspect is the need to synchronize the power generators in an electrical network to ensure a flow controllable, stable and reliable energy; this is an important feature equally shared in WLAN, the synchonization method in a protocol defines by far, a telecommunications network; not only for delivering energy purposes. As for topological considerations, in particular they are of special interest to the electricity distribution networks High Voltage Direct Current (HVDC) that are mainly used for transporting large volumes of energy in network topologies with comparable characteristics to the point to point links of the telecommunications networks.

In the connections HVDC there are highlighted the following advantages [28]:

- "High stability of the links, since the flow of energy is rapidly controllable.
- The sense of the flow of energy is easily reconfigurable
- There are no technical limits associated with the distance of the link"

Finally, from the service point of view also there is a coincidence in essential components of the power delivery system [28] that is: clients, sources and the system of delivery of energetic services. In consecuence the conception of these processes from the optics of the business is also equivalent.

VII. ENERGY-ORIENTED TRANSMISSION PROTOCOL ISSUES

Whatever type of stations and receiving antennas (whose directivity plays a major role in conditioning levels of transmitted signals), to perform the wireless power transfer, it is required to integrate electronic techniques, signal processing and radio frequency methods, which have been implemented successfully for WiFi [6] for transport energy wirelessly.

According to [6] the implementation, essentially is based in sending preset frames, designed to have an average energy level higher than an average conventional transmission information, this achievement is made in several radio channels simultaneously. For delivery information, periodically are sended useful frames between these energy patterns or alternatively an exclusive channel for sending information used is set.

At the remote node, energy harvesting techniques are applied to retrieve and store much energy as possible. However in the context of a network with distributed resources as the ad hoc networks, it should be defined the mechanisms that the nodes require to interact between them, according to principles and policies that should be part of the communications protocols that implements this network.

An initial approach of the problem of research is make it part of the implementation of an effective communications strategy, in the particular case when exists the need or desirability of delivering power to a privileged node, as much as possible, even at the expense of the availability of other network nodes. A situation like this can happen when the consequences of the disruption of a critical process are equal to or more expensive than the indefinite unavailability of the network. It seeks to maintain the operation or "survival" of the node with priority, the value of resources or mission of this node it justifies extending their autonomy.

A service with the features described here, will be useful in the implementation of sensor networks with low energy consumption, monitoring of assets or people and where energy autonomy of a node may be the most important variable, such as during conducting an experiment, in a rescue operation, in a recording or playback of content, in space exploration when the permanent operation of a remote probe is a priority, etc.

A. NODE ROLES

Following roles are established:

i. The node beneficiary, receiving, storage or last node.

ii. The node dedicated, hub, or final escort.

iii. The node partially transmitter.

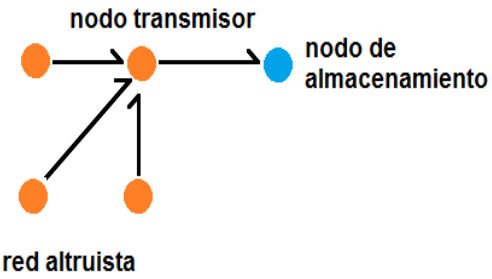
B. ENERGY TRANSMISSION SCENARIOS IN AD HOC NETWORK

The following graphs illustrate several simple schematics of some possibilities in a protocol that offers services of transmission of energy in an ad hoc network, in the states that are described later, the usual parameters as the permanency of the nodes, the efficiency, the energetic optimization. The availability of the links of the network are not relevant and can go on to a second place.

In agreement with a typical characteristic of some ad hoc networks, where it exists a condition of equality for all nodes, the protocol must include a later phase where the nodes that are unavailable, are waked up, transmitting them in turn energy in some certain moment. For what a minimal remnant of energy must exist in every node, sufficient to operate the circuits, waiting for a request of power. If the time of wait is excessive it will not be able to wake up.

Following scenes are defined then:

"Fig 1 " Altruistic network with a hub/transmisor :



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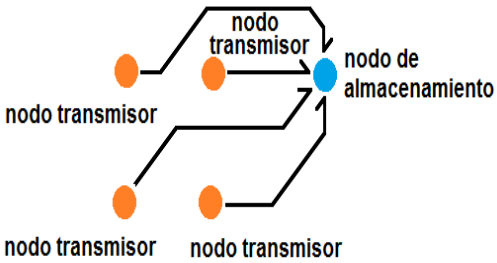
a. In this case the network makes the best effort to deliver energy to the nearest node to the receiving node, either by availability of links, distance considerations, priority, etc.

In this scenario there are two surviving nodes at the end of the process of power transmission and occurs under conditions where eventually the visibility of the remote node is minimal, that is, the critical node is only connected to the ad hoc network via a single link. The network shows an altruistic behavior, which can reduce their availability to a minimum in function to keep operating at two nodes. In this case the cluster network takes control of the resources and becomes the last "escort" node.

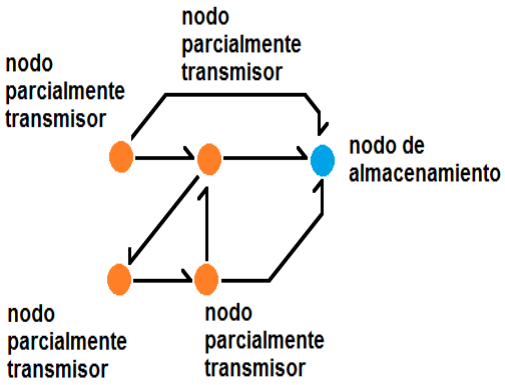
"Fig 2" Altruistic network with multiple nodes dedicated transmitters:



b. Here are several nodes which that can be linked to the receiving node, therefore so many channels as nodes on the network that has visibility with the critical node are required.

As in the above scenario the network is altruistic, capable of sacrificing availability. In this case the cluster-head of the network takes control of the resources of the management and ends once enters in unavailability condition. As in the previous case this node is in a dormant state, unable to run more than just a passive listening. In that sense, the network as such it disappears and at final, there is only one node that was who received the power of the network.

"Fig 3" Network with multiple nodes not dedicated transmitters:



It is surely the most common scenario, here the network chooses the nodes that will be able to be beneficiaries temporarily of the energetic resources, whereas the network continues its normal operations.

Though it it may be seen as an altruistic network because in the long term eventually will be affected the availability, no real sacrifice exists because all nodes will eventually negotiate their resources and will benefit in some way. This is the most challenging scenario from a technical standpoint since it must keep a balance between providing information and energy transmission.

VIII. FUTURE WORK

For the great quantity of interactions between the nodes of the network, the scope that is given to this first phase of the work is a conceptual approach, which will be tested from simulations in a later stage. Bearing in mind that the simulation is frequently used for the exploration of complex systems of telecommunications [29], since the processes, decisions and definition of variables occur largely in the software or hardware that makes up these systems, it is possible to obtain a reasonable approach to reality at reduced costs. These computational tools also allow relatively easy way to model and measure variables of stochastic type associable to different types of telecommunications traffic and facilitate performing various virtual experiments.

There are several challenges in the elaboration of a protocol with these characteristics, first must be defined if the nodes of the network once they reach a declared critical operating state, they can break free of itself, this has security implications that are outside the scope of this article and should be analyzed in a context of risk of any energy attacks. Similarly environmental considerations, neither were part of this research, however, are of most importance, since in a network with high power density in the wireless medium may eventually generate situations of risk to the environment, people and animals.

The next technical developments in this field will broaden the horizon of technology creating new environmental and legal technical challenges in the use of telecommunications networks, since to be defined limits the possible uses of power transmission wirelessly. This leads to the need to improve mechanisms to evolve the existing regulatory system in the communications sector, so that acceptable conditions set for all stakeholders in line with market requirements.

IX. CONCLUSION

In view of that in the recent years they have come improving wireless telecommunications technologies, partly with the intention of increasing the rates of transmission of information and partly to address in some measure the demands of energy that need the nodes to operate, capacity power transmission constitutes an important advance in reducing dependence on their own sources of power and converts the energy into a fully managed resource in the different energy strategies based on distributed management of network resources telecommunications.

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