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Elaboration of a communications protocol for AD-HOC networks oriented to energy transmission

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Dedicated to my precious children Santiago, David and my adorable wife Yoli, for their love, patience and understanding, who are the engine of my life.

To my beloved parents Graciela and Darío, for their love, unconditional support, sacrifices and advice that always motivated me to continue achieving this great goal.

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Abstract

Through this work, is made an analysis of the technical aspects related to the energy transmission in personal area networks environments (PAN) and its potential use by means of wireless devices of common use, with the employ of ad-hoc networks that use standard protocols of communications over Wi-Fi and that simultaneously transmit information and energy.

It begins with the exposition of the most relevant physical variables, evaluating the most important considerations from a service orientation viewpoint and taking borrowed as reference, some techniques of the protocol engineering. Constantly is presented the state of the art in points of special interest in order to illustrate the eventual requirements that should be addressed for obtaining an effective energy transmission through the technological means currently available.

It is showed the equations considered, the physical and logical components as well as the models adopted in the analysis of the wireless energy transmission process. It is presented the topics key in each layer of the Wi-Fi communication protocol stack, under the guidelines of the IEEE 802.11n standard and the possible improvement actions suggested from a theoretical perspective, which are then consolidated in a basic simulation scenario throught a set of rules implemented in the NS-3 communications network simulator, using its native classes, functions, libraries and reference codes for wireless applications.

Keywords: WPT, ad-hoc, energy, wireless, Wi-Fi, protocol, NS-3.

Resumen

En éste trabajo se realiza un análisis de los aspectos técnicos relacionados con la transmisión de energía en redes de área personal (PAN) y su potencial utilización mediante dispositivos inalámbricos de uso común, de manera que a través de las redes ad-hoc que utilizan protocolos de comunicaciones estándar mediante Wi-Fi, se pueda transmitir de manera simultánea información y energía.

Se inicia con la exposición de las variables físicas más relevantes, evaluando las consideraciones más importantes tenidas en cuenta desde una orientación a servicio, tomando como referencia algunas técnicas de la ingeniería de protocolos y presentando constantemente, el estado del arte en cada punto de especial interés con el fin de ilustrar los eventuales requerimientos que se deberían abordar, con el propósito de obtener una transmisión de energía efectiva mediante los medios tecnológicos actualmente disponibles.

Adicionalmente se presentan las ecuaciones consideradas, los componentes físicos y lógicos más importantes así como los modelos adoptados para el análisis del proceso de transmisión de energía inalámbrica. Se ponen de presente los tópicos relevantes en cada capa de la pila de protocolos de comunicaciones inalámbricas bajo el estándar IEEE 802.11n y se sugieren las posibles acciones de mejora desde una óptica teórica, que luego se consolidan en un escenario de simulación básico a través de un conjunto de reglas implementadas en el simulador de redes de comunicaciones NS-3, con sus clases nativas, sus funciones, sus librerías y códigos de referencia para aplicaciones inalámbricas.

Palabras clave: WPT, ad-hoc, energy, wireless, Wi-Fi, protocol, NS-3.

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Introduction

From ancient times the term *energy* was a generic reference that symbolizes dynamics, actions and achievements. Parallely, it was also known the different properties of the nature related with forces and other manifestations as the movement caused by electrically charged things, the magnetic interactions between materials, the lights and the sounds produced in the atmosphere, etc. Consequently was quite common in the human quotidien experience the utilization of the term *energy* and in fact, nowadays is well known that the energy is something that is needed to realize every little aspect in our lives, we need energy for everything and also the nature needs energy too.

As an example (and probably it is an inadverted situation) many of the companies of productive sectors are also energy providers without being completely conscient of that. Enterprises like the manufacturers of food products, the industry of sugar products and many enterprises of sweet drinks, do deliver of energy for their customers. These products are just one form and an example of how is performed a physical transfer of quantized amounts of energy, an analogy of the interaction between servers and clients. In the present document is explored another form of energy delivery for one specific case, studied in the environment of wireless telecommunications systems.

The energy is a fundamental magnitude and a characteristic of the entities of the nature as are the matter and the information (from a physical point of view). The energy is well defined in a quantitative way as was explained by Leibniz’s kinetic energy equation, the Boltzmann’s energy thermodynamic equation, the Planck's quantum energy equation and the Einstein’s special relativity equation. If these mathematical expressions are transposed, it is possible to interpret them in function of the resultant dependant variables. For example, it is possible to express that once applied the scale factor, the unit conversión processes and the application of mathematical operators, the matter turns out to be equivalent to another forms of the energy. Then is possible to express that the energy is everywhere and even also that, it is possible to transport it as was exemplified in the previous paragraph.

In classical physics the foundational principle behind these mathematical expressions is the law of conservation of the energy, which establishes that it is not possible to generate the energy in a strict sense, only is possible its transformation and neither is forbidden its transfer. By other side, the qualitative definition for the energy is still elusive and there are only a few descriptions availables; energy usually is presented as the capacity of doing a work. This abstract definition allows to define the energy delivery in terms of the transfer of the capacity of doing that work.

Returning to the classical analysis of the electromagnetic theory, the energy requires a wave interpretation of the electromagnetic processes which occur in the space and the time, this analysis led to the concept of density of energy that has been used from XIX century for understanding the energy transmission and by extension its transport. As is understood in the Maxwell's electromagnetic theory, the energy transfer is a process continuous, local and causal from one point to another point. Both in the time and in the space, and this is formulated in the electrodynamic continuity equation. This basic mathematical principle defines in accurate way the process of the energy transfer. The magnitudes involved in this continuum processes are in function of the time and the distance. The containers of this energy can be physical particles, field waves or electrically charged matter.

It is important to indicate that in the absence of a physical or tangible media (that is called the vacuum), it is also viable to transmit the electromagnetic waves as was explained and mathematically modeled by Maxwell. The ideal vacuum is considered the perfect wireless media and the behavior of the electromagnetic wave both in the theoretical vacuum as in the air, is quite similar in terms of the values of the physical relevant constants (despite the fact that the air is a perceptible and relatively dense media).

The physical properties of the air are relatively constants under several different conditions. The air media has its own advantages: it is ubiquitous, it is accessible to everybody, it is inexpensive from a logistic point of view - at least until today, in spite of the fact that the use of the electromagnetic spectrum is clearly not inexpensive. However, given the nature of the propagation of electromagnetic waves, the air is a dispersive media (and this is very important), with high levels of attenuation for the electromagnetic signals. Furthermore, the air does not limit well the electromagnetic interference because it is a shared medium.

With the pass of the time, the technological advances have been permitted to control these processes in a better way, allowing to manage the dispersive nature of wireless media. That was used for the first radio transmissions and for the transmission of information (from a point of view of information technologies). Even it was feasible to transfer energy wirelessly without modulation processes as it was demonstrated by Nikola Tesla in their experiments and patents, where were used sparks and induction processes for transfer energy through space, by means of the use of high potentials and big signals emitters. Then, in a primer conclussion, it must be said that in any kind of wireless communication process, always there has been implicity processes of energy transfer.

From a technologically approach, the information is an attribute that is injected and extracted from data and those data are transmitted by waves through physical matter (in electrical conductive or non electrical conductive media) with the participation of the digital and analogue signals processing technologies. The theoretical advances in physics have allowed the appear of technological devices that soon found an use in the incipient communications enterprises. That created a virtuous cycle during the XX century that consolidate the invention of radio transmission technologies, and produces the television broadcasting, the transistor, the programming languages, the integrated circuits, the internet, the personal computer and the mobile phones between other important developments.

The components and devices that allows this processes are not made only of hardware as old days, it has been needed great amount of code lines and software for governing this processes and today that processes are controlled by computers, even in the mobile devices; using procedures developed in standard programming languages. In the former communications industry fifty years ago was usual that big companies embraces the entire develop of a technological product and controls vertically all the development and the production chain of a new technology, even they had the capacity to create the programming languages involved in the development process.

Currently, every single year the communications and processing processes have become more and more complex (in fact they are extremely complex). This industry has evolved to convert it in the current information technologies industry, that englobes both the telecommunications industries as the hardware and software industries. Nowadays the main companies of this sector are also the most powerful enterprises in the world.

By the hand of the advances in miniaturization of electronic components and the advances in all the fields of information technologies, the development of new technologies is a crossed-multilevel effort with considerable invests of capital and many teams conformed by highly specialized technical experts. The products are built and oriented to satisfy specific market niches and with the purpose to comply with specific business models objectives.

The development and deployment of a technology asset as a wireless protocol is a challenging task that is developed in many technological fields. For example in the industry of software, many independent teams build the new applications and develop the underlying needed layers for their operation. Frequently key players of the market have its own strengths in some of the process in the physical layer or in the link layer process development. Others actors, could be leaders in operating systems or in middleware development áreas and many others are strong in the development of applications. In the same way some manufacturers have developed skills highly specialized for developing and building specific components as radiating elements, amplifiers, etc., and others enterprises are exclusively focused in semiconductor devices, in microcode assembly languages, etc.

Nowadays in the information technology world, when a new technology arises after a process of communication between the key industry players, the results of the consensus are consolidated by influential standard organizations. Then the initiatives are proposed to the world technical community and published in the form of drafts of standards of the industry. These documents are finally adopted to some extent by the IT industry. With time those drafts are converted in oficial documents and are maturated in a permanent cycle of standard evolution.

After this quick review and antecedents, in this document is presented an approach for transferring and delivering energy by means of waves in an wireless media. It is analyzed some specific communications protocols as a support to provide energetic resources to remote clients through energetic services and it is simulated the process through definite conditions. The present work is based in a commercial communications wireless system, that was developed from an industry standard.

The energy constraint is a typical problem of mobile devices and it is usually addressed with optimization techniques and estimations of the use of the energy in every node, through schemes of management and energetic profiling models for creating forecasts to predict the best policies applicables. The nodes in this type of networks, usually implements protocols oriented to reduce the electrical power in certain circumstances or to reduce the performance. However, with the proposed new energy transfer capabilities in the nodes of an ad-hoc network, the range of alternatives for supplying energy to the nodes it is notably increased. The order of magnitude of the distances involved in the processes analized in the present document is about one meter, althought in principle there would not be no restrictions associated to the distance with a reasonable treatment of the gain of the radiant antenna system and the adoption of adequate signals processing techniques.

A technology like this will be useful for interchanging (by demand) the energy in a wireless tlecommunications network. Given the fact that the nodes of a wireless network could appear or disappear in any moment, it is not always possible to have a well defined underlying wireless infrastructure, then an ad-hoc network connectivity approach is the better way for creating the links to establish a network. Typical requirements from a network node could be to extend its lifetime, to get enough energy autonomy for doing a specific task (like in wireless sensor networks) or increase the availability of the entire network.

Currently there are several research fields related with this topics and very often are focused on the development of new electronic appliances and its probable uses. Complementary in recent times has been explored many ways of improving the performance of digital and analog systems, even including new wireless processes with the explicit objective of transfering more energy. The state of the art can be explored in the standards and in the frameworks of the industry like in the ITU reports (ITU-R, 2016) and in the profuse technical literature published in the field. Only just a little sample of the vast number of publications available, was used in the elaboration of this document. I hope it will be useful for you.

1. Wireless energy

According to the principle formulated by Claude Shannon, which states that it is possible to get a channel practically free of error probability if the data transmission rate is lower than the information capacity of the channel (Cover & Thomas, 2012). This concept could be extended for the radiated energy in a transmission and would allow to get also a maximum value of energy associated for each combination of link parameters, within the limit of the information capacity of the cannel (Grover & Sahai, 2010, pp. 2363-2367). That limit defines the possible coding schemes, modulation techniques, data rates, and other variables, in order to have both a data communication link and an energy channel link. This would be the energy capacity parameter of the channel, and for wireless media this metric it must considers the electromagnetic propagation elements.

This application has been explored previously and is a under-development technology by the date, with potential to be a disruptive technology by its market possibilities, information systems security-related concerns, biological implications and different uses, boosted by technologies like IoT[1], 5G[2], dron technologies, changes in regulations (Federal Communications Comission, 2017), the use and exploitation of renewables energies (Congress of Colombia, 2014) and the wireless grid (Tak, A., & Ustun, 2016). There is a relatively long history of efforts about it (Visser, 2017), and it is available different commercial products (Analog.com, n.d.), exists consortiums (Retrieved, n.d.) (Airfuel, n.d.) with standards released (Qi, n.d.) (IEC, 2017), and roadmaps from industry and top

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[1] Internet of things

[2] Fifth generation of wide area wireless technologies

manufacturers (Qualcomm, 2019) (Shoki, 2014). As a matter of fact, technical standards on the subject are incipients even in developed countries, then it is timely to create focused groups in educational institutions, in regulatory bodies and in the technical community, just as occurred with the successful Wi-Fi and Bluetooth. For sure, in the next few years it will be see commercial solutions related in some ways to part of what is presented here.

There are a wide range of strategies to deploy energy-efficient telecommunications networks, from the search for energy optimization in the nodes to the development of energy-efficient transmission and routing techniques in the ad-hoc network. Nevertheless the simple transfer of energy, through radiating techniques it is also possible and it is explored in this document. From a functional point of view, in the wireless ad-hoc[3] networks, the nodes have to adapt to the media conditions and to rise by themselves a communication link and other coordination mechanisms. In this environment and in particular in mobile networks (MANET[4] non-vehicular) there is a availability restriction associated with the amount of energy usable in each node to maintain the network, therefore it is necessary to identify alternatives that allow efficient use the energy available in the network (seen as a whole).

Further developments related with the basis and principles presented in this document, could extend its scope to a new category of telecommunications services. Given the facts that currently there are not available commercial solutions in this field and governmental regulation is a pending task, the Wireless Power Transfer in Far Field antenna zones is a promising technology, possible and affordable; whose applicability merits study and analysis.

[3] Ad-hoc Networks: These are telecommunications networks without a permanent infrastructure

[4] MANET: Mobile Ad-hoc Networks

The scope of the presented work is developed under the radiating WPT[5] environment, in order to carry out the transmission of energy, through antenna arrays, wireless electronic devices and by means of intensive signal processing techniques, which have been successfully implemented for Wi-Fi (Talla et al., 2015). This interaction it is established in the context of a network with distributed resources in its nodes such as ad-hoc networks. The mechanisms that the nodes uses to interact, must be defined according to principles and policies in the stack of communication protocols availables for this networks.

The Wi-Fi technologies are practical implementations of subsets of IEEE[6] 802.11 standards and are released and controlled by the Wi-Fi Alliance[7]. In the present document it will be explored the technical requirements extracted from these technologies to design a communications protocol for energy transmission in a single hop of an ad-hoc network.

1.1 Energy and power

Wireless Power Transfer technologies (WPT) rest on the literal premise that exists a kind of power flux between the interacting nodes, although from a strict physical sense is the energy what results transferred. Usually the *Power* is defined as a flux of energy and in this sense the expression *Power transfer* is probably at least, a redundant expression. However, that nomination has been widely spread and is currently the most common denomination for the underlying processes that will be described in this master dissertation. Thus, its use it will be employed through the present work only in case of

[5] Different to near field R-WPT: Resonant Wireless Power Transfer, because Radiated WPT it is used in the far field zone of the antennas.

[6] Institute of Electrical and Electronics Engineers is a registered trademark.

[7] Wifi Alliance is a registered trademark

need, else, will be emphasized the energy-oriented character of the physical process involved.

Despite the fact that the energy transport in electromagnetic waves remains in research(Valagiannopoulos, C. A., & Alu, 2015) and that in mobile networks there are frequent interactions with the antenna near field both in transmission as in reception, in this document the meaning of the term *Power* (when it is used in a wireless environment) it will refers to far field generic rate of energy flow in a surface, energy current(Kaiser, 2011) or Poynting vector, regardless the speed of delivery of the energy or the energy density concepts.

The expression Energy Wireless Transfer, is not uncommon in literature (Stanford University, n.d.) (RTCGroup, 2019), however nowadays Wireless Power transfer it is more frequent in the industry. In the same way, by the state of the art, some terms and concepts has not completely standardized and the entire technological domain as others, is under constant review by the industry.

1.2 Wireless energy measurements

In mobile devices, for an energy delivery process it would be prefered a simple metric of energy transfer, just like the wired counterpart where it is obtained from the Circuit-Watt-Law evaluated over a period of time or from a estimation of the hardware components like battery energy capacity components or capacitance. However, since the variability of wireless media due to nature of wireless media and fading mainly, the difference of several magnitude orders between the source emitted power versus the power captured in the receiver, and the fact that the existing metrics are based on DSP[8] processes; the conventional measures of energy transfer are finally, indirect methods.

[8] Digital Signal Processing Techniques

One of the most common parameters is wireless energy measurement is the associated energy per bit rate. This variable can be understood as an intelligibility metric, because it gives the value of a symbol strength over the background noise in a given environment. In any case is an information metric and not a physical measure. This parameter are usually associated to *m-ary* modulation schemes as a way to differentiate the signal quality of every one of them, is essentially an over-the-air quality of signal metric. Exist another indicators like the RSSI[9], LQI[10], PRR[11], BER[12] metrics, that performs a estimation of the signal strength or wireless link quality and are useful for coordinating some interactions in a wireless protocol (Lee, Y. D., Jeong, D. U., & Lee, H. J. (2010, 2010), nevertheless it must be cleared that it not provides a confiable estimation about received energy because first, they are not oriented as an energy indicator and second, they are oriented to the telecommunications link parameters quality.

Even more, about these metrics, there are different opinions in the technical community about its benefits (Srinivasan, K., & Levis, P. (2006, 2006)(Srinivasan, K., Kazandjieva, M. A., Jain, M., & Levis, 2008). In addition, the manufacturers interpret independently the parameter and each one choose their best way to implement the indicator. As a result, there is no complete clarity about what to expect from indicator like RSSI. In recent years IEEE 802.11n and IEEE 802.11 ac standards, have introduced an improved RF-channel metric called as RCPI[13]

[9] IEEE Radio Signal Strength indicator

[10] Link Quality Indicator

[11] Packet Reception Rate

[12] Bit error rate

[13] Received Channel Power Indicator

The classical link parameter estimation it deploys a complete power delivered calculation from RF[14]-emitter to RF-receiver, in this traditional method the losses in the propagation channel are estimated in power terms (dBm[15]) according to an arbitrary propagation model. Also it is calculated the Poynting density power vector indirectly through the specification of directivity or gain of the antenna system as a fixed data sheet value, while in the real RF channel, the instantaneous value of electromagnetic fields, inside and outside the wireless adaptors is defined by the antenna systems orientation geometry parameters, the DSP control decisions and the MIMO[16] implementation, the burst-shaped traffic, the broadband transmission spectrum effects, and the common interferences in ISM[17] channels; as a consequence this metrics could be unsatisfactory for a connection-oriented energy transfer protocol in a IEEE 802.11 link.

[14] Radio Frequency

[15] Logarithmic estimate of Power referred to one milliwatt

[16] Multiple input - multiple output

[17] Industrial Scientific Medical spectrum bands.

2. Energy as a service

Bearing the state of the art in the remote transmission of energy and information in a traditional communications channel, it turns out possible to consider in the nearly future the provision of services of energetic type on a classical telecommunication network, this is the underlying concept called *Wireless Grid* (Q. Wu, W. Chen, 2015). Though still there has not been commercialized such application, the *Energy as a Service* model (EaaS) is a potential new use of the channels and an alternative business that can exploited by telecommunications operators in high public affluence zones and by end point users, using smartphones or portable devices operating Wi-Fi.

The technology that could be conceptually compared with WPT in communications channels is the PLC[18] technology, which provides telecommunications services through electric power lines and is one of the basis of SG[19] services. These technical environments are clearly distinguishable, since in SG for data delivery it is employed the wide-area physical infrastructure of transport and distribution of electricity, while in PLC is used in a LAN[20] environment. The implementation variables and niche-markets differ ostensibly. However, in both fields of application there are some common uses such as home automation, wireless access technologies, green technologies among other potential future destinations.

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[18] Power Line Communication

[19] Smart Grid

[20] Local Area Networks

The wireless energy transmission technologies enclose a wide variety of technical fields that mainly search to improve the performance of the existing radiocommunications technologies, to improve the global efficiency of telecommunications systems or to take advantage of electromagnetic coupling in emitters of electromagnetic radiation in the near field area (like the NFC[21] technologies). As an examples it is included the wireless chargers for consumer electronics, the wireless chargers for electric or hybrid vehicles and the *Radio Harvesting Technologies* which are closer to the scope of this work.

In addition to the transmission of energy by the wireless media and the technologies that deliver data through the power supply lines, there are several technologies that make use of the optical spectrum such as:

- Wireless communications technologies in the infrared radiation wavelengths with scattered light beams, with wide use in known devices for domestic use, less known are the IEEE[22] 802.11 infrared capabilities.
- The FSO technologies, which were initially designed to transmit high rates of information through coherent light beams in the visible or infrared spectrum.
- The VLC technology that makes use of the optical spectrum with scattered light sources. The transmission of data making use of the light sources in the offices and in the homes of the users.

Both in the case of VLC[23] and FSO[24], it is technically possible to get remote energy from these sources of electromagnetic radiation, although the energy density is not comparable

[21] Near Field Communications

[22] Institute of Electrical and Electronics Engineers

[23] Visible light communication

[24] Free-space optical communication

with that currently provided by the sun through solar cells which is a mature technology. However, these areas are subject to research and development to improve existing or to build new applications. These topics are out of the scope of present work.

To define the roles of the nodes of the ad-hoc network in the energy service, it has kept in mind the same distribution scheme that already exists in traditional energy distribution networks, except that some of the precepts under which these are designed do not apply to wireless networks, such as the concepts that energy cannot be stored because it is used immediately, the roles are fixed in the transaction or that the orientation of transmission is predefined (although its direction and distance could be variable for mobile nodes).

For a energy service in a wide wireless grid over an ad-hoc network, the guidelines under the entities would be modeled are the following (Casazza & Delea, 2010) :

- Energy can be produced in one location and transmitted to another.
- Energy can be transformed in every ad-hoc network node to other classes of energy and used in different ways.
- A power system is composed of client nodes (sinks), generation nodes (sources) and a delivery system (wireless media). It requires more than two nodes.
- In every energy transaction there is not an external arbitration entity or ad-hoc network cluster head.
- Client nodes (sinks) are the load of the system and have particular patterns of consum which have different impacts on the ad-hoc network and in their operation.
- The delivery system carries the energy from the generation nodes (sources) to client nodes (sinks).

- Electromagnetic conversion processes AC/DC[25] are produced in the generation nodes (sources) and in the client nodes (sinks).
- A client node (sink) can eventually become a generator node (source)
- A node in the ad-hoc network would be a client or a generator or both at the same time
- The network management is done by the same nodes that arranges the transaction
- The use cases exist in two levels, at the level of the service and at the level of the ad-hoc network protocol that manages the physical resources.

2.1 Physical layer considerations

For the energy transmission protocol scope of the present work, it was selected a commercial broad-diffuse ISM technology that alleviates the present and future challenges of electromagnetic compatibility and interference with other systems, in addition it was considered that it works in PAN[26] areas with line of sight engagement and high throughput for reducing the time dedicated to communications channel and increase the energetic frames. This protocol will be modeled in present work and simulated in NS-3 simulation framework.

These arbitrary high-level features were chosen thinking in simplicity of the service, future ease of deployment, availability of open source software (as far as possible) and availability of eventual hardware component for testing the protocol[27], however the scope

[25] Alternating Current / Direct current.

[26] Personal Area Networks

[27] Currently this functionality is released by Wi-Fi Alliance as Wi-Fi Aware, is supported by Android Oreo O.S. and in some products of hardware manufactured by Samsung Intel (AC 8265), Broadcom (BCM 4261) and Qualcomm (AC2 Chipset).

of this initial work it is only the basic communication protocol as a basis for the wireless energy service. Additionally, IEEE 802.11 has several physical protocols useful for this purpose, however based in a concept of social networking justice[28] it was selected a protocol with beamforming basic capabilities. As a consequence of the previous requirements the standard IEEE 802.11n(IEEE, 2009) it was selected.

The justice concept used here is based on the principle that every node receives what is previously agreed, therefore other nodes can not access these services justice precept. It is justified in the specific need to secure the delivery of the scarce energetic physical resource, which is linked directly with the high-level requirements of Energy as a Service and it is related with another social behaviors in ad-hoc wireless networks as equity.

In spite the disadvantages of wireless networks in this topic the goal is to reduce the probability of delivering energy to nodes that are not properly authorized, because it could to mean to loss valuable energetic resources in the nodes or in the network, and this yields to loss the control of resources, possibilitate an energetic attack against the ad-hoc network or not guaranteeing a due compensation to the members of the ad-hoc network. The last, it means for a client that will just receive what is capable to pay or exchange for, no more, no less. To the generator, server or source it implies that its energetic resources will be well employed, accounted, and rewarded[29] in a way as efficient as possible can be, and that for this it will be not needed to maintain a record of trust for cooperant nodes in the ad-hoc network.

[28] Based on ad-hoc networks social behaviors studied by the TLÖN researching group and the social guidelines of the network operating system S.O.V.O.R.A project, developed by the group.

[29] In this part are mentioned some of the IEEE 802.11n features and also the most important protocol-to-design characteristics. In chapter 3 will be explained with greater detail.

There are several mechanisms to restrict this undesirable access and probably the better way is to try to establish physical layer control through a highly directive point to point wireless link between the server and client, to limiting the visibility to other nodes, by confining the useful physical angular beam transmitted for the antennas as restricted as possible with the support of beamforming feature, which is an useful feature available in IEEE 802.11n and further advanced standards. It is also possible to establish complementary mechanisms of authentication, QoS, accounting and billing in upper layers of the protocol; those projects are out of the scope of the present work.

The IEEE 802.11n protocol was released in 2009 (IEEE, 2012) and includes the MIMO techniques up to four antennas, channel bonding, throughput increased up to a maximum of 600 Mbps, advanced coding, backward compatibility developments and many other improvements in channel management, roaming and power saving. It operates in unlicensed bands, allowing more non-overlapping channels than previous versions, some of them fully useful in bands in upper bands (placed in 5 GHz spectrum part) as described in Annex A.

From the analysis performed on this frequency allocation options, according with the general service parameters and the technology selection criteria explained, it will be used the bands[30]:

36 (5180 MHz)
48 (5240 MHz)
44 (5220 MHz)
40 (5200 MHz)

[30] See B Anexes: 5 GHz IEEE 802.11 Bands

One criteria is that it was authorized its utilization in several countries including Colombia[31] for wireless AP[32] and for wireless clients, in indoors spaces as unlicensed bands[33]. In the deployment cases this is a desirable feature for the compatibility with previous communications systems and for the interoperability issues in the devices commercially availables. Additionally these bands are intended for spread spectrum communications given their low power associated, currently it is difficult to extract enough energy for power supply or storage in the receiver, although there has been success in several international efforts in this field (Zeng, Clerckx, & Zhang, 2017).

These frequencies as well does not require advanced characteristics like DFS[34] and TPC[35]. In ad-hoc IBSS[36] DFS mode is not employed; complementarily, in energy transfer systems either is undesirable the power restriction indicated by TPC. In addition, for the propagation characteristics of the 5 GHz wave, their application for energy transmission will be restricted to a line of sight environments in short range devices communications. Given the points in common with later standards it is highly probable that a protocol of energy transmission based on the recent IEEE 802.11ac release improves its features, however IEEE 802.11n is less complex and is a mature and consolidated technology.

[31] Resolution MinTIC 00473 of 2010 chapter II article 4.7 and Resolution MinTIC 2544 of 2009 Title II article 11

[32] IEEE 802.11 Access Point

[33] Unlicensed National Information Infrastructure UNII-1: 5150-5250 MHz

[34] Basic Service Set IEEE 802.11 Dynamic Frequency Selection.

[35] Basic Service Set IEEE 802.11 Transmitter Control Power.

[36] IEEE 802.11 Independent Basic Service Set

For preserving fidelity with real world in the NS-3 simulation of the protocol, it is key considers the practical RF-signal limits currently defined in different jurisdictions especially for transmitted power levels and because highly directivity antenna arrays have also power restrictions directly related with their joint antenna system gain. From the analysis of regulations at to date, this topic it will be condensed as a typical system gain and will be described technically in next chapters.

From the regulation perspective, the transmission system system must operates in chosen bands that it will be applied for an AP a maximum power spectral level that not exceeds 17dBm in any 1 MHz band and an antenna gain that does not exceed 6 dBi; for a client the maximum level must be 11 dBm (Federal Communications Comission, 2014) for any 1 MHz band and a maximum power of 250 mW according to FCC 47 CFR 15 part E (15.407) (CORNELL LAW, 2020). For testing, the requirements are detailed in ITU-R M.1652-1 Recommendation, about the DFS detection threshold, channel availability, non-occupancy period and channel move time(ITU, 2011).

For this, the IEEE 802.11n currently available implementation[37] in the NS-3 simulator has a high flexibility to define specific channels, the channel bandwidths, the MCS[38] parameters, physical and link protocol features and also the typical RF link parameters in the simulation as the propagation model, the link distance, the antenna system gain, data traffic libraries, mobility models and a basic energy set of measurements. This level of customization in real-world, is only available by manufacturers as a design request for its hardware distribution brands in highly specialized laboratory testbeds. Complementarily NS-3 simulator include the most common communication protocols, with a high grade of detail (for example high level internet protocols).

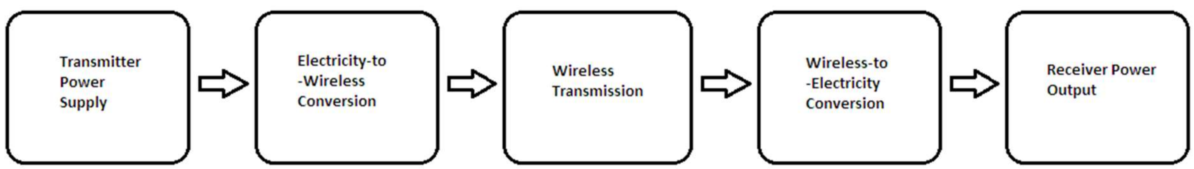
[37] Currently NS-3 simulator latest release is the 3.30 revision (August 2019).

[38] Modulation and coding scheme

2.2 High level model

An abstraction of the processes in power terms is suggested in the following figure (Zhang et al., 2018) being the transmitter the node that delivers energy and the receiver the node that stores and uses that energy:

Figure 2-1: High level blocks of a wireless transmission system



Source name: Adapted from (Zhang et al., 2018).

The communication protocols involved in the subjacent communication process described here are fully bidirectional and the wireless nodes of the wireless networks have mixed roles in the communication process; usually in a few milliseconds it will be several messages in both ways, additionally the traffic shape in WLAN environments is a burst traffic type. However, in a conceptual approach from a server-to-client analysis, always will be possible differentiate the key parts of the services related for a better understanding of the nature of the transactions and for this reason are presented step by step the high level stages of the physical parts of the process.

In first place it should be explained that in ad-hoc networks environments the transmitter power supply must be a finite source. That means from a philosophical and conceptual approach, that the powered plug devices and permanent power sources are not considered as ad-hoc node sources because they are by definition fixed located sources and they are a kind of power infrastructure, which is opposed to the concepts of ad-hoc network or ad-hoc network node. However the applications that detach from nodes with a power infrastructure are very important from a practical point of view and are useful as a wireless power spots or reliable generators (which is out of the scope of this document). For the present work, chemical powered nodes (for example Ni-Cd, Li-Ion, Lead-acid batteries) MANET[39] nodes and alternative powered nodes (like solar cell fueled devices) are also valid ad-hoc nodes (Kim, S., Vyas, R., Bito, J., Niotaki, K., Collado, A., Georgiadis, A., & Tentzeris, 2014).

In consequence, an ad-hoc telecommunications network it is not necessarily by definition an ad-hoc telecommunications mobile network, then it is possible to have an ad-hoc network member in a fixed location and in practice, is highly probable that this node has a fixed infrastructure energy and additionally and that this node uses a high gain antenna system. In that case it would not be considered as an ad-hoc energy node. The reason is because for a given node the feature of being an ad-hoc energy network member it is independent of the feature of being an ad-hoc telecommunications network member.

The second process to consider it is the process of **Electricity-to-Wireless** conversion. This is a demanding energy activity, because it is needed to maintain a minimum level of energy for operational systems and additionally a constant energy level for the transmitter operational processes. The wireless NIC[40] cards for example, are components that demand relatively significant amounts of energy and for establishing ad-hoc networks is required at least one NIC for every node. For characterizing these processes it is important evaluate the air-interface energy consumption and delivery, and the operational node consumption. For the first the efficiency of the antenna system it is determinant for understand the conversion process between the DC[41]-power and the over-the-air

[39] MANET: Mobile ad-hoc networks

[40] NIC: Network Interface Card

[41] Direct current

electromagnetic signal[42]. In the second one, the approach used here is to employ an energy consumption simplified model, given the amount of variables to consider. As will be detailed further, the key variables will be the TCP protocol configuration and the IEEE 802.11n basic features(Sun, Deng, Sheshadri, Zheng, & Koutsonikolas, 2017).

The third process is the RF[43]-Wireless transmission by definition is a dispersive process and currently is a highly inefficient and insecure part of the system and only through MIMO techniques is affordable for energy transmission (channel modelling, signal fading modelling, space-time block coding, spatial-division multiplexing[44]) because through beamforming techniques it is possible to increase the power density and by means of physical antenna arrays and their DSP[45] circuits, the elevation and azimuth of the transmission are managed and tracked by the nodes. Those are the technical reasons for choosing the IEEE 802.11n standard, however these features are available in other commercial wireless technologies for WLAN[46] and for wide area utilization[47]. Ideally can be conceptualized as a highly directive beam like a laser-focused application.

The efficiency parameter employed in this work is a simplified multiplicative factor based on the LoS[48] intuitive Friis Propagation model. There are no specific considerations for

[42] In state of the art development was reported a microwave antenna efficiency of 79%: (Chen, C. Fumeaux, 2017)

[43] RF: Radio Frecuency

[44] See for some details in: (Paul, Thomas, 2008)

[45] Digital Signal Processing

[46] For example IEEE 802.11 ac

[47] LTE and Wimax based technologies.

[48] Line-of-Sight

interference multipath, dynamic antenna system gain, transmit beamforming, MIMO physical layer configurations because by definition are included in the channel processing of the IEEE 802.11n protocol.

The fourth process is the **Wireless-to-Electricity** conversion is commonly known as Energy Harvesting when it is considered as an energy transport process from various sources or without any formal communication processes in a one-way passive environmental listening-oriented process. Essentially can be modeled as a specific purpose antena (called rectenna), a wideband diode semiconductor and a capacitor that stores energy in a battery system through a DC-to-DC conversion process. Currently the low levels of harvested energy and the inefficiency of the conversion processes make impractical the wireless-to-electricity conversion (As a reference in 2.4 GHz ISM-band was reported an energy storage of 1.62 mJ, usable as a power of 13.51 nW, from a field with a incident power density of 15 uW/m2, with a global efficiency of 17%) (A. K. Ermeey, A. P. Hu, 2016). However it is available in technical literature some advances in direct usage of this energy, without storing in local batteries (Talla et al., 2015).

It is important to note again that always is needed energy for operational systems. In some sensors applications or RFID technologies the external energy stream it is enough for maintain shortly this processes during the transactions. Instead, currently for IEEE 802.11n it is not possible yet, then it must be a permanent energy source for the receiver operational processes. The wireless NIC cards, even in listening modes spend a significant part of the energy of the wireless nodes.

2.3 Quality of service

The usual parameters of quality considered in telecommunications networks not always are required in an energy transmission. In the way that is formulated in present work (related with transfer time), for the energy transmission only the aspects concerning to the availability of the link are relevant. Given the fact that energy networks already exists and that the key parameters for an acceptable service are commonly known, this huge previous developments, in this document it is desired to highlight the equivalences in a broad sense, that the two networks (electrical wired and communications wireless) have in common from a hierarchical and topologically point of view.

Before, it is needed to present the main difference between them, related with the many orders of magnitude of separation between its power[49], in the following table it is suggested an arbitrary set of variables associated with possible power values in these systems with the purpose of comparison.

Table 2-1: Power comparison between a traditional electrical system and a wireless energy transmission

Network	Typical Electrical Power (W)	Access time to network	Infrastructure	Line	Link distance	Service	QoS[50]
Electrical wired network	20 x 10 E + 9	Instantly	Hard, wired, fixed	Electrical circuit	Shorter than the wavelenght	On-premises based. Non - causal	Standard
Wireless energy network	20 x 10 E - 9	Variable	Soft, ethereous, not fixed	Virtual circuit	Many times the wavelenght	On- demand based	Customized

Source name: own-elaboration

[49] Other variables as Electrical potential difference (Volts) and Electrical intensity (Amps) are secondary, because the service is on demand and its value depends of the link distance which it is not a constant.

[50] Quality of service

This considerable difference of magnitude it is not a real barrier to formulate the basic entities and principles that are part in the energetic wireless transfer processes, because technology is changing, new services are evolving, new devices usually requires less energy to do the same tasks, it is unpredictable the state of the telecommunications technologies in a few years, in communications technologies it is not uncommon to have such differences of magnitude as for example in the electromagnetic spectrum which is used in the scale of several meters wavelengths and in the nanoscale wavelengths also.

Even in telecommunications links between earth and remote probes are received signal levels of 10 E-16 Watts (Caltech. NASA., n.d.) while are transmitted signals of 20 E+3 Watts (Rogstad, Mileant, & Pham, 2005). However in grace of the discussion, and as was said before, in the best of the author’s knowledge and as a far as could be established in literature, currently it is not commercially available energy wireless transfer technologies in WLAN environments.

Then, considering the E-service, as any other energetic service provided by a network like traditional electrical transmission service, it is possible to make a comparison between some entities and its features. For example, the hydroelectric, thermal, eolic or nuclear generation systems are equivalent to the energy conversion process from chemical sources to electrical systems, which is verified on electrical batteries with independence of the specific chemical process or battery technology associated[51]. This process is the most frequently conversion process in energy in ad-hoc networks.

In the same way the transformation station or substation of the electrical network corresponds in an ad-hoc network to the process of changing the media (wired media to

[51] The term generation is conceptually not accurate because the real physical effect is a conversion in the type of energy. For example, in the hydroelectric generation process, the kinetic energy associated to the water flux is finally converted in to electrical energy associated to the flow of charges in electrical conductors. Talk about generation of energy is contrary to the energy preservation physical law: the energy is not created or destroyed, only transformed.

wireless, wireless to wired media) for the electromagnetic signals and the modulation, demodulation, coding and decoding processes required to send the energy through wireless media[52].

The network of distribution it is not a fixed network as the electrical infrastructure, instead it is established under a demand concept and corresponds to dynamic RF links with an adjustable antenna system directivity and gain.

The receptacle in user area in the electrical systems, corresponds to a virtual connection established by a communications protocol. It will be natural to consider a TCP socket like a real energy socket, because in its origins that was the analogy realized by the designers of this transport protocol.

In relation with the power problems associated to the energy delivery in the market of regulated energy it exists a commercial synthesis in nine classes of events (Eaton, 2015). In the following table it is realized a cross-reference between the service power in a classical electrical network in terms of quality of service and in a wireless energy distribution ad-hoc network single hop equivalent estimate.

[52] An antenna equipment can be understood as a impedance transformer connected in the interface between two different media propagation for electromagnetic signals.

Table 2-2: Power comparison between a traditional electrical system and a wireless energy transmission

Electrical service infrastructure network problem	Wireless network energy delivery service behavior
Power failure	Link unavailability
Power sag	
Undervoltage	
Switching transient	
Frequency variation	Wireless channel change
Harmonic distortion	
Power surge	Traffic burst, throughput increased, overflow
Overvoltage	
Line Noise	Throughput decreased

Source name: own-elaboration

From the above, the problems that impact the traditional electric energy service are different than the problems that arises in a wireless ad-hoc energy network. While the change in RF channels is controlled by link layer protocols according to the values of measurements of the conditions of the wireless media related with noise, interference, throughput, errors and retransmissions, all these parameters are linked to availability of the optimal conditions for the wireless transference of data. In the case of improving the conditions, it is possible to achieve an increase of data traffic in the channel, which not necessarily indicates that RF fields are stronger, but as a minimum refers to an adequate transmission condition. Then, from the optics of the wireless transfer of energy, the priority is to maintain the availability of the RF link and to secure a minimum level threshold for the receiver.

As a consequence the need in a wireless energy transfer network in to increase the on-the-air time for signals. Neither the quality, quantity[53] or cost[54], by other side the reliability is by default low in a wireless environment. For wireless systems with a high standards of availability or reliability, the typical solution is the deployment of fixed infrastructure that improves the probability of access the network, with the least access time.

Passing to an analysis from the network perspective, in order to achieve or control the quality of the energetic services for every node of the network, it must be needed to measure, or at least to estimate the energetic resources of the network. That feature of the network is called the capacity sizing of the network, also it has to be considered a forecast of the energy states in the network and the variability of the demand associated to the energy and to the time required to provide it. These attributes define for every potential client a concept called the value of the service (Willis, 1997).

Depending of the services profile that characterize a specific ad-hoc network it is possible for an entity of superior order in the network, to register or manage the energy transactions in the network. In ad-hoc networks these nodes are known as cluster heads and in principle, any node could be a cluster head depending on the dynamic evolution of the ad-hoc network.

[53] This service evaluation approach is known as the quantity and quality (Two-Q) analysis in the electrical distribution sector. (Willis, 1997)

[54] This service evaluation approach is known as the value volume in the electrical distribution sector. Willis, H. L. (1997). (Willis, 1997)

Additionally, it exists another criteria linked with specialized attributes of the network, that kind of functions are deployed by the agents of the ad-hoc network. When it is considered all together the result is an ad-hoc network with behaviors. The agents of the network could have attributes linked to optimal performance of the network, decision making based on artificial intelligence, game theory parameters or even in social-based behaviors.

From a network energetic perspective the basic “instinct” of a node, agent and network itself, it would be to maintain or increase their availability. Nevertheless, given the fact that the ad-hoc networks by definition are oriented to service more than to maintain the network infrastructure, it could be analyzed other behaviors for nodes and agents in order to optimize the services uptime or for the prioritization of specific network distributed process. Understanding the network as a set of resources, it is not strange to find specific agent actions oriented to sacrifice process or even network nodes, for achieving a greater or most important network global goal. Although this thematic is very interesting, it is also very deep and complex, then these high-level network features and considerations are out of the scope of present work.

Finally, the measurement of the services delivered is done by quantification of E-frames delivered in the single link. Given the fact that even without MIMO techniques it is possible also, to deliver energy in an uncontrolled and inefficient way, the connection orientation for the physical layer it is not mandatory. In the link layer also it is possible to have the two scenarios, both connection oriented or the connection-less scenario, in the transport layer by contrary, the concept of connection-oriented protocol for energy delivery it is needed for having a billing control. In the same way in the network it is required an specific agent instance to check reputation or buying capacity, these capabilities of management are associated with ad-hoc social network entities or ad-hoc network institutions that build, regulate and maintain service databases.

In consequence for the energy services billing, the subjacent concepts in every energy transaction are based first, in a social precept of network justice (as was explained before in the physical layer general considerations) in which every node receipts what it paid for[55]. Second, in confidentiality and data security concernings for the physical, link and transport layers; because as is well known, wireless transmissions are natural broadcasting communications and very often this attribute is highly undesired.

[55] This is guaranteed by physical layer beamforming IEEE802.11n features.

3. Protocol stack

The energy oriented transmission protocol is in essence a connection oriented protocol. This means that is required a formal channel establishment and a previous resource reservation in each node, just before to initiate the energy delivery process. This link behavior is demanded given the high-level design requirement for the creation of a basic energy session between two peers.

Although wireless media communications are by definition a non-reliable communication by the nature of the non-guided channel; the energy transaction considered in the present work, must be a well-defined operation, even in the case that exist frequent retransmissions or packet loss, because is a formal service susceptible to be measured or managed by the nodes or by network agents in the context of a supervised or conscient action of the network executed and motivated with an specific purpose. This is a subject of interest in distributed operating systems, virtualization and network management systems, out of the scope of present work.

Taking in to account that the specific media conditions are usually evaluated for negotiations in the physical layer interaction between the nodes and in higher-level protocol of the protocol stack, it is important to remember that the common communication and throughput parameters do not conditionate the establishment of the link because for energy transmission the main considerations are the power density (Physical Layer Parameter), the availability of the link and the time on-air of the transaction, even with low data rates. In the same line of thinking, the connection-oriented feature of frame retransmission, error correction, sequence preservation are desirable for reliable data links but not indispensable for energy sessions.

From the last statements, and as an in advance conclusion, it is evident that current commercial protocols availables are not well suited for energy transmission because they are oriented to optimize or improve the data communications links and sessions. In summary, in link layer and superior layers, the usual data transfer considerations are secondary in the context of the energy protocol proposed.

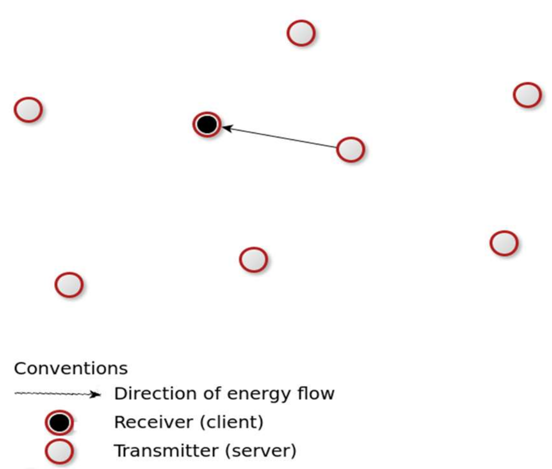
With the motivation to construct a highly focused terminology on energy, it is proposed to use the terms E-frame for a traditional IEEE802.11n frame when its payload contains data for support energy transfer services. In the same way it will be used also E-packet referring to routing data units or networking data units with energy related transfer payload, and E-datagram referring to transport or superior PDU[56] when it is used to support energy services. In a broad sense it will be employed the E-protocol term also.

[56] Protocol Data Unit

3.1 Physical layer considerations

For defining how it will interact the nodes within the network, the simplistic scenario is shown in Figure 3-1. The energy delivery service is established in a telecommunications wireless link, considered in proximity with other nodes, where it is possible to build an ad-hoc network based in a peer to peer basic connectivity. By definition the energy transfer is a half-duplex service on every link.

Figure 3-1: A service of energy delivery from one node to other node (PTP)



Source name: own-elaboration.

Without mobility considerations and only for quantifying the physical magnitudes involved and its order of magnitudes, it is possible to estimate maximum values from classical antenna equations and FCC regulations. The hypothetical electrical values received from a common Wi-Fi infrastructure network, between an access point without restrictions of power supply and a wireless node are presented in a first approximation (it not include propagation losses, fading or scattering) [57]:

[57] See Appendix A for detail the mathematical equations considered

Table 3-1: Theoretical electrical calculations for a energy delivery service from a SISO Wi-Fi AP in 5 GHz bands for Fresnel zone limit distance.

PTX(W)	EIRP(W)	c (m/s)	f (Hz)	λ (m)	NF (m)	PRX(W)	<S> (W/m²)	Em (V/m.)	G(dBi)	Ae RX (m²)	P OUT(W)
0.25	0.95	299.79E+06	2.40E+09	124.91E-3	0.25	1.51E-3	1.93E-03	1.21	6	4.94E-03	9.52E-06
0.25	0.95	299.79E+06	5.18E+09	57.87E-03	0.54	69.60E-6	19.06E-06	0.12	6	1.06E-03	20.22E-09
0.25	0.95	299.79E+06	5.20E+09	57.65E-03	0.54	68.54E-6	18.62E-06	0.12	6	1.05E-03	19.61E-09
0.25	0.95	299.79E+06	5.22E+09	57.43E-03	0.54	67.49E-6	18.20E-06	0.12	6	1.04E-03	19.02E-09
0.25	0.95	299.79E+06	5.24E+09	57.21E-03	0.55	66.47E-6	17.79E-06	0.12	6	1.04E-03	18.44E-09

Source name: own-elaboration

Where:

G: Antenna gain fixed by government regulators in dBi units

PTX: Output conducted power fixed by government regulators in Watts

f : Central frequency of Wi-Fi Channel in Hertz

λ : Wavelength at central frequency in meters

D : Maximum physical length of antenna for one radio in meters (Typically are dual band 2.4/5 GHz)

NF: Distance maximum of Fresnel zone (Near Field) in meters

<S>: Intensity or medium value of energy-flow vector (medium value of Poynting's vector) in Watts per square meter

Em: Maximum value of electric field in receiver antenna in Volts per meter

Ae: Effective aperture of receiver antenna with equal characteristics to emitter antenna in square meters

PRX: Available power in antenna terminals in Watts

The following table shows an estimate of power values in Fraunhofer region (Far field zone) only varying link distance for figure 3-1, the other parameters are the same of table 3-2:

Table 3-2: Theoretical electrical calculations for a energy delivery service from a SISO Wi-Fi AP in 5.18 GHz band in several link distances.

PTX(W)	EIRP(W)	c (m/s)	f (Hz)	λ (m)	X (m)	PRX(W)	<S> (W/m²)	Em (V/m.)	G(dBi)	Ae RX (m²)	P OUT(W)
0.25	0.95	299.79E+06	2.40E+09	124.91E-3	1.00	98.81E-6	7.86E-06	0.08	6	4.94E-03	38.87E-09
0.25	0.95	299.79E+06	5.18E+09	57.87E-03	2.00	5.30E-6	105.49E-09	0.01	6	1.06E-03	111.94E-12
0.25	0.95	299.79E+06	5.18E+09	57.87E-03	3.00	2.36E-6	20.84E-09	0.00	6	1.06E-03	22.11E-12
0.25	0.95	299.79E+06	5.18E+09	57.87E-03	4.00	1.33E-6	6.59E-09	0.00	6	1.06E-03	7.00E-12
0.25	0.95	299.79E+06	5.18E+09	57.87E-03	5.00	848.43E-9	2.70E-09	0.00	6	1.06E-03	2.87E-12

Source name: own-elaboration

Where:

λ : Wavelength at central frequency in meters

X: Distance between transmitter and receiver in meters

<S>: Intensity or medium value of energy-flow vector (medium value of Poynting's vector) in Watts per square meter

Em: Maximum value of electric field in receiver antenna in Volts per meter

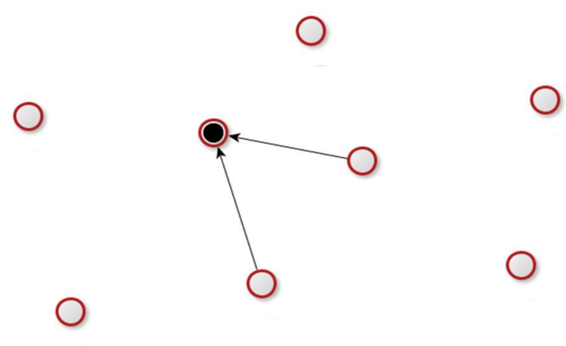
PRX: Available power in antenna terminals in Watts

From table 3-1 and 3-2 it is important to show the remarkable effect of the link distance in the reduction of available power in the receiver antenna terminals. With another considerations like the limited spectral space of service, the typical line-of-sight restricted behavior for 5 GHz bands, and the currently maximum power levels regulations; a practical useful energy value demands a link uptime service time for several hours.

Additionally, the higher throughput rates vs the higher energy transfer rates, are not simply related because the more complex the modulation schemes, minor is the spectral energy per bit. Also, given that energy per bit is a probability-bit-error oriented indicator because higher *m-ary* modulation schemes require more energy for achieving an equivalent SNR[58] level that inferior modulations schemes, it will be assumed that is better to use basic modulation schemes that guarantees a low traffic signaling channel for maintaining the service link and for eventually maximizing energy delivery. The criteria for optimizing those processes are out of the scope of present work, although through this document it will be presented several hypotheses and assumptions in order to get the better conditions for the energy delivery.

The following graphics present another types of simple energy transfer services:

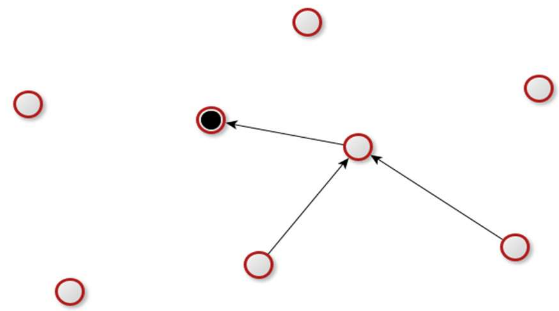
Figure 3-2: A service of energy delivery from more than one node



Source name: own-elaboration.

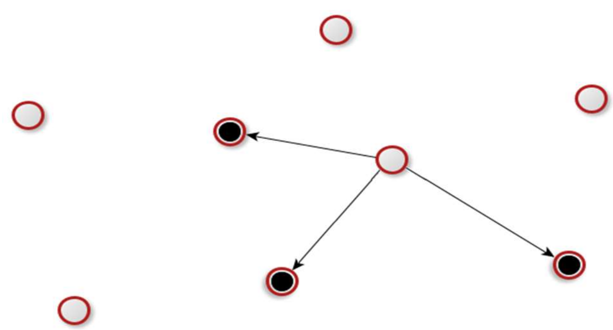
[58] SNR: Signal to noise ratio

Figure 3-3: A service of energy relay in a network



Source name: own-elaboration.

Figure 3-4: A service of energy distribution in a network



Source name: own elaboration.

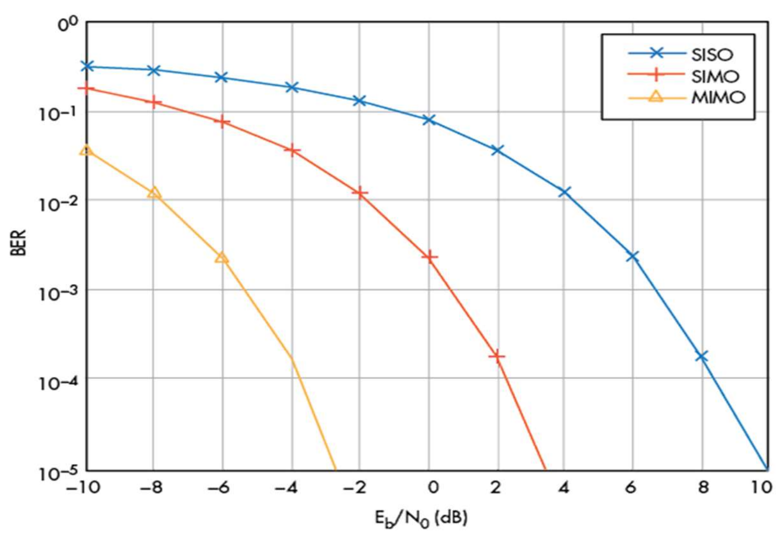
For these cases (not included in the scope of the present work) it must be needed to replicate the basic two-node configuration in a mesh environment. The protocol stack supports the point-multipoint P-MTP configuration as full-full-duplex topologies, through complex antenna diversity features, MIMO processing functionalities, MAC and IP addressing schemes, multiple TCP and energy delivery transfer sessions. In the end the energy storage it is the same for any energy transaction. Emphasis must be account in the frequency selection to avoid in-the-air destructive interference between different energy sessions.

Also, it is important to highlight that the ad-hoc nature of the network involved and the one-hop transfers it is preserved, then the routing capabilities of the devices are needed to be able to deal with different IP class addressing and eventually several physical ports for a node. Even with multiple energy sources and receivers in a small space in the transport layer it is supposed than a unicast approach is adequate for manage the transactions and for efficiency improvement. For physical media the reference standard in WLAN environments is the IEEE 802.11s wireless mesh protocol.

3.2 Energy level estimation

It is important to say that energy delivering wireless services are not specifically-ruled currently and for this reason it is used regulations of general RF devices and specifically Wi-fi applications. One of the benefits of MISO/SIMO/MIMO techniques is to offer enhanced level of signal. For purposes of increment the energy of transmitted bit MIMO option is the better one (See figure 3-5).

Figure 3-5: Signal-to-Noise levels



Source name: (Gentile, 2017).

With the same value of signal level noise, MIMO has higher bit error rate. Otherwise expressed, with MIMO deployment, sensitivity levels are lower for a fixed BER and less energy is required for each bit received. Nevertheless, for energy delivery higher levels of signal above the mean level of noise implies stronger EM[59] fields. Then, with the same levels of output power in a transmitter antenna, a telecommunications channel with a better SNR enables the possibility of getting higher levels of energy in the receiver antenna terminals. According to FCC the power would be N^2 times from an individual transmitting antenna (being N the number of array antenna elements) ("Directional Gain of IEEE 802.11 MIMO Devices Employing Cyclic Delay Diversity," 2013). In practice, the government regulators like FCC constraints this energy level by limiting transmitted power until levels considered secure or appropriate from an EMC[60] perspective, in function of the antenna array gain estimated for every possible configuration of the emitter beamforming.

When environment characteristics remains stable, it is possible to model the complex physical MIMO effects, through a high gain single SISO link like the default NS-3 parabolic-antenna-model. In this document it will be considered a maximum transmitted power under the current restrictions. Given the current predominance of this regulator and the marked North-American prevalence of IEEE standards, directional gains values are chosen from limits detailed in the FCC reference documents. In practice, manufacturers must follow this maximum values, and for the directional gains of antenna that exceeds 6dBi, the power spectral limits must be reduced by limiting transmitter power[61]

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[59] Electromagnetic(s)

[60] Electromagnetic compatibility

[61] FCC CFR 15.407(a)

About the fading concerns and Doppler effects compensation, it is possible to generate a code shorter or longer that reduces temporarily the reductions of energy levels associated to the randomness of the wireless channel. Then, the shifting of the relative phase of the symbols employed in the communications link, will change the instantaneous electric and magnetic fields intensities in the receiver and as a consequence of this, the resultant energy levels will be increased. However, the process to optimize this parameter is beyond the scope of this proposal and requires the deployment of a power control loop between the communication peers.

The physical orientation of an energy transmission protocol requires anyway, that another layers could be considered. As a matter of fact, hardware and internet protocols considers as a de-facto standard the internet stack. NS-3 simulator is not the exception, its Wi-Fi implementation includes this features in helpers and it is proposed in several code examples.

But nevertheless IP complete features conceptually it is not needed in the present work, because energy delivery is at first established as a one-hop service between a high level server protocol and a client by means of a low level protocol entities (source energy and sink energy nodes), it must be needed for common operating systems in order to establish a TCP socket. That feature would be useful in large ad-hoc networks because through IP it is possible to create a virtual energy delivery with a remote transaction with a local delivery. In this scenario it is important also, the integration a routed energy messaging protocol. This scope is beyond this protocol.

Both client (sink) as server (source) create an energy session (E-session)[62], in this session the server numerates the frames, by default the source only is allowed to have

[62] It is adopted the classical physical theory letter W as the symbol for radiating energy.

one E-frame awaiting confirmation. Once is delivered an E-frame successfully the client answer with a E-acknowledge frame (E-ACK) confirmation. The amount of energy delivered is determined by an algorithm based on time elapsed, RSSI[63], efficiency and number of frames. It is proposed the following empirical energy indicator (See equation 2.1):

$$E = N \cdot RCPI' \cdot t \cdot \eta \qquad (3.1)$$

Source name: own-elaboration

where:

N: is the number of E-frames (integer)

E: is an Energy estimation (in Joules)

RCPI': is an indicator of signal strength (in Watts)[64]

t: is time (in seconds)

η: efficiency (in %). Is a non-linear empiric factor that depends of random environmental RF variables. It will be considered as 100% unless it will be said in another way. It not includes antenna efficiency or internal DC/AC-AC//DC efficiency, neither modulation processes or circuit efficiencies.

For a real deployment (beyond the scope of this work) it is needed the implementation of ISO/IEC/IEEE 8802-11-2012. 18.3.10.7 (OFDM PLCP sublayer - PMD receiver specifications) and 20.3.21.6 (HT PMD receiver specification) in every wireless network

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[63] The IEEE 802.11n equivalent to Received Signal Strength Indication but in Watts, RCPI original specification it is created in dBm.

[64] ISO/IEC/IEEE 8802-11-2012. 18.3.10.7 (OFDM PLCP sublayer - PMD receiver specifications) and 20.3.21.6 (HT PMD receiver specification) it defines RCPI as a measure of power in dBm the selected OFDM PHY channel for a received frame.

card. Usually manufacturers have available wireless NIC with ad-hoc functions in OFDM 801.11a or in 802.11 b/g (Intel, 2019).

Recently Wi-Fi Alliance launch the Wi-fi Aware Technology, that it is essentially an IBSS service over 2,4 GHz and 5 GHz. It is uncertain until the date if it is available in commercial devices in HT[65] (802.11n) with OFDM for IBSS ad-hoc networks, although it is allowed in the 802.11n STD, and there are chipset capable to set a IBSS in 802.11n standard (Cypress, n.d.). However this functionalities are available in NS-3 simulator. Currently there is not yet available commercial hardware for Wireless Energy transfer over Wi-Fi in the antennas far field zone.

3.3 Link layer general considerations

The energy service is a simplex transaction in essence, from the source to the sink, cause the energy delivery it is transported by definition only in one direction. Nevertheless the signalling of the channels that support him are half duplex and the data messaging in full duplex because IEEE 802.11n assign different frequencies for transmitting and receiving. Given the fact that OFDM delivers energy in parallel streams is a half duplex communications with frequency diversity, but no redundancy. The features of synchronizing (or timing at least) avoid ISI[66] and are useful for consistent billing services in business-oriented application layers.

[65] High Throughput rate

[66] Intersymbol Interference

In the present proposal, the transport layer is lately in charge of conforming a reliable service, because traditional IP services are best-effort designed and wireless environment are unpredictable. In consequence, the IP addressing scheme it is complementary to the physical addressing provided by MAC addresses found in NIC cards. However and conceptually talking, for establishing a basic addressing feature for a one-hop connection-oriented service it is enough providing a physical addressing scheme.

By other side, in the eventual existence of a business-oriented layer (which is future work) through of an Energy Application, with remote services that uses a remote Energy Protocol, the retransmission of datagrams commonly controlled in transport layer could be controlled instead by a higher layer; because the reliability of the E-datagram it will be controlled by specific application layer based on a circuit-switched oriented parameter as the permanency of the link, instead of a packet-network oriented parameter like the order and consistency of data, which is the main feature of an connection oriented transport protocol.

IP Layer services are commonly supported by the internet protocol stack, nevertheless only for ad-hoc networks composed by many members or for ad-hoc networks with gateways to another external networks, it is required the use of networking addressing schemes like IPv4 or IPv6. IP Layer it is not mandatory in the scope of present work, because the energy delivery have as a basis a one-hop reach definition. Although in large ad-hoc networks it is possible to create a set of virtual energy delivery services through a remote transaction protocol with a local delivery. In this scenario it is important to integrate at least a third-party transaction server or ad-hoc agent through a internetworking routed energy delivery messaging protocol. These considerations are proposed as future work.

Turning to physical layer concernings, IEEE wireless channels are built with the design criteria of wireless messaging collision avoidance. The collisions are presented when wireless hidden nodes try to use the wireless media; in a traditional wireless communication network, the information will be destroyed by the event. This channel type is called CSMA-CA and is an adaptation from the wired media channel type based on collision detection and is called CSMA-CD. In both, when a collision is detected, the data frames are unintelligibly and has to be re-sended, in CSMA-CA it happens when it is finished the message delivery and after the collision is notified to the nodes. It is not a 100% perfect media arbitration and in this process it is also possible that the channel be taken for another station not involved in the initial interaction between the original nodes and delaying even more the access to wireless media and the information delivery.

By other side in an energy transfer it is not important the collision event, because the focus is to keep operating the link as much as possible until time connection is finished. In the case of the E-protocol the persistence of the channel it is very important and the collision not necessarily impact the service delivery, because the transmitted data are always known and does not transport any information. Only signaling transactions result of some importance. By these reasons re-transmitted E frames (made by default in the TCP connection oriented protocol) are not a priority and in any case the time count associated to the energy delivery it is not affected. Summarily this is not the way that traditional wireless communications operate, because for data communications does not have sense to let to lost data intentionally or accept corrupted data.

Is for that reason that an energy transmission, is a synchronized service in a packet network with a connection oriented transport layer. The E-frames delivery have priority over collisions and over the requests for other stations. By consequence the media is reserved by nodes or the network while it is performed the energy transaction. The first initial steps to establish the channel and services are informed in a broadcasts as usual, but the energy delivery employs the beam-formation feature of IEEE 802.11 channel. Once is finished the transaction, the media is released without notification, given the fact that another stations were aware of the operation. For the stations unaware d of the transaction it simply will be a normal IEEE 802.11 contention situation once the wireless media has been released.

In any case for avoiding the monopolization of the media, E-frames or E-services have a limited predefined time. This is a sensible tuning network parameter that must be optimized for a real environment. IEEE 802.11n networks fill the wireless channels 40 MHz channels with 57 of 144 possible subcarriers when it is not operated in legacy mode.

Though energy channels are defined by design as 40 MHz OFDM channels, OFDM is not the best way for delivering energy because spread the energy in several bands which requires several receptors to harvest, diminishing the energy total available cause there are losses increased by the amount of additional hardware. By other side, beamforming compensates this handicap. A better wireless energy transfer protocol (near to an ideal RF environment) would be FDM, without specific power restrictions, with a set of narrowband licensed frequencies, with a dedicated and independent in frequency signalling channel, with MIMO capabilities, with beamforming features, with line-of-sight directional tracking capabilities, with high directivity antennas and preferably far of living forms. Given the fact that most of this requirements are impractical or undesirables, the present work is presented in real-world devices and protocols and the eventual deployment in this environment should be inefficient, unorthodox, difficult to adapt and probably unuseful.

3.4 Transport layer considerations

Before initiate the transport layer features of the protocol, it is important to express that in NS-3, TCP and UDP are part of the internet stack libraries and functionalities. By this reason as default, it is needed to define an IP addressing scheme for the nodes involved. In this case for energy delivery the simplest condition is a link between nodes through a directive antenna created channel, similar to a channel established in a wired media. Then a class-D IPv4 type it is enough for formalize the superior layer processes.

The transport protocol is in charge of support unicast stable data connection, once the physical parameters has been setted. With a low MCS and a minimum throughput, the concerning in the transport protocol is to assure a channel for the energy transactions, because the permanence of the link is an important parameter in the energy delivery protocol. By the nature of the energy delivery transaction it is considered that unicast and connection oriented is needed in the protocol and in consequence TCP is the best option in this layer.

The TCP is a protocol reliable which establish a mid-level secure virtual datagram channel between processes in separate computers, and is capable to support several many processes through the same channel. Controls the amount of data in the flow, it is unsensible about the nature of the physical media involved in the connection, but each connection has a time related sequence number that is established in the negotiation process depending the reliability of the connection in lower layers, also it has CRC check features for robustness.

For establish the communication between layer pairs can be used logical connectors known as sockets. For use TCP, an application creates a TCP socket as the final point of communication for the application, and are used for writing and send out traffic or for reading incoming traffic, is a local abstraction that allows to the operating system to reserve resources for the communication processes (Tanenbaum, Andrew S., 2011); sockets are created from the IP addresses of the endpoints of the communication, a transport protocol and the transport ports of the nodes.

Given the distances involved and the point to point orientation of the service in physical layer, it will be considered that the frames will be delivered in order. For TCP, in the case that the ACK message is lost and the Energy server retransmits the energy frame, the receiver identify the number of frame and answers with the n+1 ACK number of frame, because every frame its identical in its payload. If two consecutive ACK are lost, the sender will finish the transaction and session with this client. This is important because wireless environment usually it has unfavorable conditions and the participants dont have warranty of successfully delivery of the energy which is a limited a precious resource for being wasted. This means that for energy transmission the TCP transmission window will be 2.

The client must have a register of sequence number of the two last frames for comparing and determine if the ACK message is lost. This implementation serves as a flow control between nodes (by default it will be considered that for two stations Tx transport protocol window and Rx transport protocol window are equivalent).

3.5 Application layer considerations

According to the previous explanation, the implementation or development as a commercial product in current conditions is a long and hard work. With existing technologies probably it is not feasible the implementation and it would be better a new development from the scratch, oriented to energy transmission from the beginning, which combines the best of wireless communication technologies and energy transfer advances. By other side, a complete high level-protocol specification it would be desirable and useful eventually because it would be developed with independence of the details of the physical and link layers. The processes and primitives considered could remain unchanged. This proposal neither includes business-level layer considerations that will be needed for a real context application and is out of the scope of this protocol. However were mentioned some of this basic features for future work.

The estimated amount of frames in a transmission in order to guarantee a minimum value of energy unit depends mainly of the link distance, because the data rate is the minimum as possible. The relation between the type of traffic to be transmitted and the configuration of the frames for an acceptable energy delivery service it is uncertain and has to be determined with further research. In relation with the rate adaptation and the algorithms aware of distance changes, fading, and interference for controlling the transmission rate; for energy transmission it is required to develop new algorithms, because existent control rate implementations are focused on optimizing the throughput or on to minimize the energy consumption in the node.

4. Energy protocol

Protocols are a set of rules prescribing the manner in which communication takes place, the meaning of information exchanged and the appropriateness of communication under prescribed conditions (Liu, 1989).

Given the fact that transport protocols like TCP reside in the kernel of the operating systems for consumer communication devices, the energy protocol is an application program, either in the TCP/IP stack model or in the ISO 7498-2 (OSI) layered model. The details for a real implementation depends of the host specific operating system and it is beyond the present work (Comer, 2014). However is used an equivalent subset of rules found in NS-3.

The energy transmission occurs when the client, implements a process through a request of a synchronous connection[67] that is required to a remote energy server, then a process in the server implements a service. The protocol messaging exchanges a set of primitives by means of transactions with the final purpose of establish a reliable oriented-continuous flow of data[68].

The primitives of the E-protocol are not related with the primitives of the TCP flow of data. For transport layer in NS-3 and in GNU/Linux systems, it is usual the aperture of sockets

[67] This requirement is due the need to count with an isochronous connection for energy delivery, independent of the nature of the data involved in the communication process between the nodes.

[68] For a detailed explanation of every term it is recommended: (Tanenbaum, Andrew S., 2011)

for reading or writing data, the execution of the complete set of TCP primitives[69] and its closing, which is compatible with the connection-oriented nature of the E-protocol although TCP is flexible with superior layers because accepts asynchronous application programs and it is designed for a wide spectrum of communications systems, even over circuit-switched networks[70].

These interactions occurs after the virtual data link are created and that happens after the IEEE 802.11 processes have been concluded, the firs of these processes is to secure a media for establish the appropriate channels. In order to access the media successfully IEEE 802.11 uses the Distributed Coordination Function DCF. The DCF is a process based on pseudo-random wariness, when the media is silent the node wariness-less takes the media while the others nodes await. When the media is busy the observer nodes await that the expected frame time transmitted in the header it is accomplished[71]. The minimum silent times are quantified through previously known for the nodes IEEE 802.11 Interframe Spacing IFS periods.

For avoiding as much as possible the collision IEEE has defined a series of collision counter-measures which reduces the collision probability as much as possible, that could be summarized as:

$$Pec + Pknec + Punec + Pr = 1 \quad (4.1)$$

Source name: own-elaboration

[69] Alternatively, for a real implementation there is available the socket libraries or socket calls API approach.

[70] It is related with the robustness principle of the protocol. (Ray, 1999). P. 584

[71] The timer is the IEEE 802.11 Network Allocation Vector NAV.

Where:

Pec: the probability of evident collisions, managed through CSMA techniques.
Pknec: the probability of known non-evident collisions, managed through CA techniques.
Punec: the probability of unknown non-evident collisions, managed through RTS/CTS[72] channel reservation techniques.
Pr: the residual probability of collisions, impossible to avoid for the IEEE 802.11 techniques.

The frames are transmitted in traffic bursts of 1ms compounds by groups of OFDM symbols. Each OFDM group contains up to 200 clusters of symbols of 3.2 μs, separated by Cyclic Prefix Frequency samples CP up to 800 ns. Every symbol has 52 subcarriers and every carrier transports one BPSK symbol(Qiu, 2016). The symbols are organized in IEEE 802.11n frames selon the packet format chosen. In the requirements of the energy delivery protocols it is not needed to preserve backward compatibility with previous IEEE 802.11 standards, furthermore a higher bandwidth selection reserves more frequency bands and more eventual channel capacity for energy delivery given the same electronic components in the real-world radio device[73] which is desirable in noisy environments even when the scheme modulation MCS selected it has a low throughput value, as required in the energy delivery protocol.

For effects of the present work it is hypothesized than with less information transmitted, the system has better predictability, more controllability and possibly the more energy delivered. In this sense, for OFDM the aggregation IEEE 802.11n features (D. Skordoulis,

[72] Request to send / Clear to send primitives used for reduce the incidence of the hidden node problem.

[73] For Access Point the maximum power spectral allowed by FCC CFR 47 15E (15.407) is 17 dBm in any 1 MHz Band (Equivalent to 50 mW)

Q. Ni, H. Chen, A. P. Stephens, 2008) like A-MSDU[74] and A-MPDU[75], (which are oriented to save time and processing resources in IEEE 802.3 based systems by removing common frame headers), these capabilities only present value for point to point energy delivery, when enables persistence of the data link channel, when allows a better control or forecast of the channel behavior.

The use of A-MPDU for frames sended to the media interface - lower layers is preferred over A-MSDU in wireless environments for achieve higher throughput because each subframe has CRC; however it is not clear the effect in an energy delivery environment. Then it is hypothesized that for a wireless environment the MPDU aggregation it is not desirable because intends preserve the message integrity and in a TCP transmission with high rates of packet error rate, the trend is to converge to the same values of the channel utilization that no A-MPDU usage, independently of the amount of value aggregation (Kesselman, 2007).

The A-MSDU frame conformed with data originated in top layers and only one CRC, is useful for point to point links given the fact that it is a unicast development for a single receiver, then is a desirable feature in energy delivery protocols selon was explained for the energy delivery service; this format could be make frames until 7,935 KB from the data of top layer.

Once the physical layers are structured the following consideration is the flow of data. For establish an energy transaction it is required to have permanently a data link connection, the state of this connection is controlled in the physical layer and the flow of

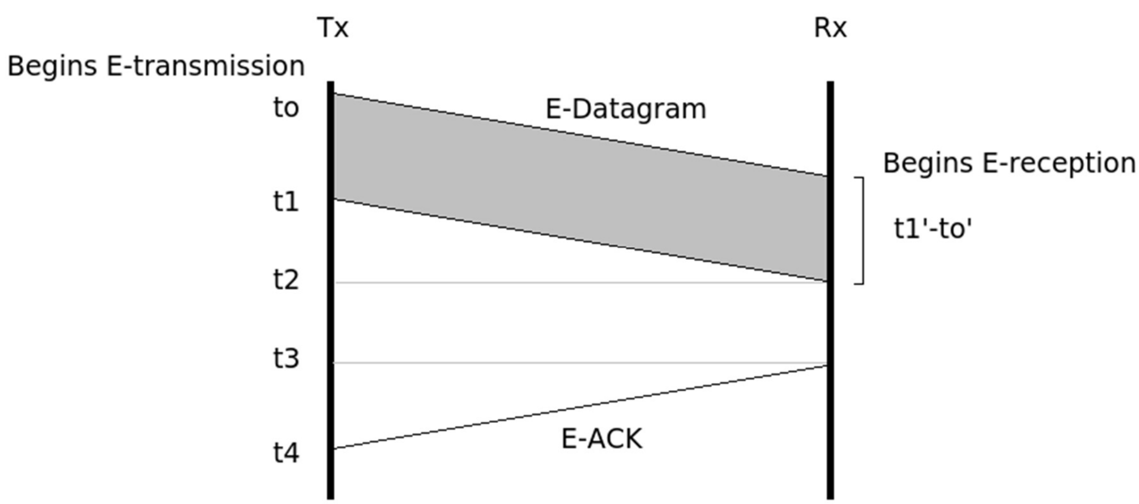
[74] A-MSDU IEEE 802.11n Aggregated MAC Service Data Unit, (MAC) MSDU is the unit of data protocol received from the upper layer

[75] A-MPDU IEEE 802.11n Aggregated MAC Protocol Data Unit, (MAC) MPDU is the unit of data protocol sended to the lower layer

data is managed in the transport layer. For energy delivery the delays in the data transmission, the order and the consistency of messages are not critical considerations, then the usual parameter like congestion windows size, the number of retransmissions and ACK of payload data are secondary because the data transferred in the datagram is a series of repeated characters. It is needed further research about if exists difference in the energy contents of the messages in relation with the data transported or the information of the datagrams, this is out of the scope of present work.

In order to determine when it is required a datagram retransmission it is needed a detailed time evaluation as follows:

Figure 4-1: E-Datagram timing



Source name: own-elaboration

$$t4-(t1-to)=(t2-t1)+(t3-t2)+(t4-t3) \quad (4.2)$$
$$E-Datagram\ Time:(E\_DT)=(t1-to) \quad (4.3)$$
$$t4-(E\_DT)\ =\ \ (t2-t1)+(t3-t2)+(t4-t3) \quad (4.4)$$
$$(t2-t1)=(t4-t3)=Propagation\ Delay\ Time:P_{DT} \quad (4.5)$$

$$t4 - (E\_DT) = 2\,x\,P_{DT} + (t3 - t2) \quad (4.6)$$

$$t4 - 2\,x\,P_{DT} = (E\_DT) + (t3 - t2) = Billing\ Time \quad (4.7)$$

If:

$$t4 - (E\_DT) > 2\,x\,(max\ 802.11n\ distance\ link \div c) + 2\,x\,(E\_DT) \quad (4.8)$$

Source name: own-elaboration

Then the transmitter must retransmit, because station takes more than E-Datagram time in process, then probably is out of reach, is off or there has been a collision. Each frame sended must be registered in local time and each frame confirmation must be numbered is registered also in local time.

Table 4-1: Primitives of service

ID	DESCRIPTION	TPDU
1	TO ASK FOR ENERGY	ASK-E
2	TO LISTEN ENERGY SOURCES	None
3	TO SEND ENERGY	SND-E
4	TO RECEIVE ENERGY	RCV-E
5	TO CONNECT TO SOURCE (PLUG)	PLG-E
6	TO DISCONNECT TO SOURCE (UNPLUG)	UPG-E
7	TO CONNECT SINK (PLUG LOAD)	PLG-L

ID	DESCRIPTION	TPDU
8	TO DISCONNECT SINK (UNPLUG LOAD)	UPG-L
9	ROL (SOURCE/SINK)	ROL-E

Source name: own-elaboration

The primitives that are used for negotiation are:
ASK-E, ROL-E

The primitives assigned for controlling the energy session the primitives are:
PLUG-E, UPG-E, PLG-L, UPG-L

These primitives would be invoked by an application, and would be implemented by a finite state machine over the set of rules of NS-3. That set of instructions in upper levels are not included in present work and is suggested as a further work, with the awareness that it would be convenient to create an entire new set of wireless-stack libraries oriented to energy transmission.

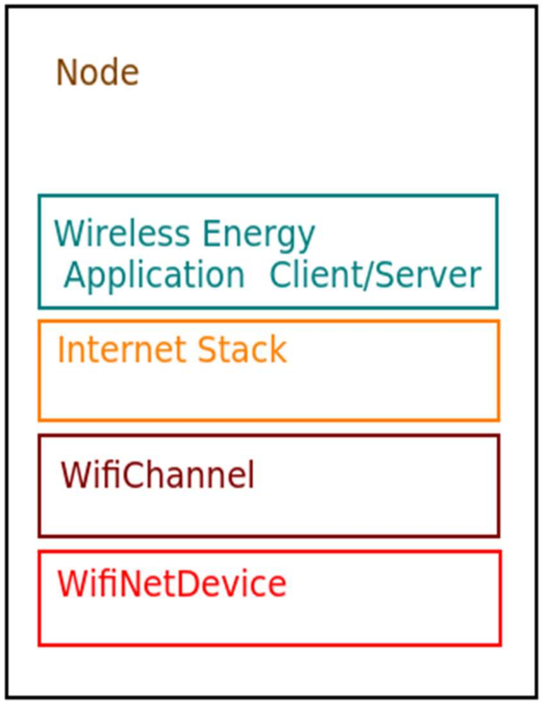
5.NS-3 simulation

Previously it was mentioned that the simulation is currently the best and in some cases probably the only way to test some of network features like the functionalities described in this document. The NS-3 simulator is a telecommunications discrete event based simulator, maintained in an open source environment, supported by a community of researchers and academic institutions in several countries, whose evolution is in charge of the Nsnam organization and the guidelines established by the University of Washington. Former releases of this initiative were made under the NS-2 network simulator framework which actually is out of support and development. Currently is at 3.30.1 release.

The simulation is a process in which is organized a set of real world abstractions of a network like wireless nodes, with specific functions assigned by software from a stack of protocols which are fully customizable. NS-3 has a set of classes for wi-fi simulations In the C++ source code of the framework, Nsnam also has provided some examples of wireless energy transfer in Wi-fi nodes. The simulation of the protocol is based on the NS-3 examples and makes extensive use of its classes, through the following explanations in this chapter it is defined the simulation scenario trying to choose realistic or objective values even when as was explained before, the technologies required for energy are not fully available commercially yet.

For the present work every node has the following basic structure:

Figure 5-1: NS-3 Wireless energy node



Source name: own-elaboration

Every NS-3 class has a similar structure, either if it is a physical world entity as an antenna or if it is a software world like a network protocol. At the end, all entities are objects with a set of attributes inherited from a functional hierarchy[76]. For common tasks are available helpers that include standard parametrization of typical attributes.

When the current state of development of a library or class does not meet the energy delivery protocol, are presented the argumentation and way of solve it. (Although there is not serious not compliance). When it is considered needed further explanation of the

[76] For a complete description of all NS-3 classes: Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/doxygen/annotated.html. Nov 1 2019

attributes, the class or the abstract entities is given an interpretation from the energy delivery protocol point of view. In general were chosen standard libraries with common functions. Notes were made where is possible to refine the implementation with more detailed specifications, proposed as guidelines for future work.

5.1 Implementation

The physical channel which is implemented by the ***PropagationLossModel ()*** class and considers loss values dependant of frequency with a linear-basic path loss model based on a free space model for the antenna far field region selon the specific ***FriisPropagationLossModel ()*** class[77].

The delay of electromagnetic signals over the air is it performed by the ***ConstantSpeedPropagationDelayModel () class.*** For simplicity was chosen a free loss space environment and the Friis propagation model, which has been proposed[78] as an acceptable model in indoor Wi-Fi environments until 10 meters[79], consider as theoretical base an isotropic radiator in an homogeneous media.

[77] By default is setted to 5.15 GHz. It is recommended for use in distance superior to three wavelengths (3*λ) which corresponds to 3*(5,8 cm)=17,4 cm in this frequency. See at: Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/docs/doxygen/classns3_1_1_friis_propagation_loss_model.html#details. Nov 1 2019

[78]See for some details in: (Paul, Thomas, 2008): P.32

[79] Usually referred as breakpoint distance d_{BP}

The IEEE 802.11 physical layer functions are performed by ***WifiPhy () class.*** The propagation media considered it is modeled through the ***YansWiFiModel ()*** class and ***YansWifiChannel ()*** channel class which are adequate to the scope of the simulations given the fact that it are not considered non-linear, non-isotropic, non-homogeneous frequency dependent phenomena[80]. The ***YansWifiPhy ()*** is in charge to deliver to the channel class the packets, the AWGN[81] errors of the channel are modeled in the ***NistErrorRateModel ().***

Given that is possible for conventional mobile Wi-fi devices to have attached high gain antenna systems typically for outdoor environments, with high physical dimensions originally conceived for point to point applications[82]; even for this applications, the maximum distance limit imposed for the propagation model (10 m) is a far field distance[83] and by consequence the NS-3 propagation model chosen is valid.

The same consideration is valid for other antenna systems like high gain monopole antennas[84] and antennas with parabolic reflectors[85]. However, for the present document it is considered only indoor conditions between 1 to 10 meters, although for some indoor

[80] Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/reviews/2016/socis-final/wifi-design.html. Nov 1 2019

[81] Additive White Gaussian Noise.

[82] For example the 19 dBi panel high gain antenna: See: (Ventev, n.d.)

[83] For this antenna panel, the far field distance calculated from $FFD=2*D^2/\lambda$ equation is 10 meters.

[84] For example the 12 dBi monopole high gain antenna: See: (Balticnetworks., 2019)

[85] The parabolic reflector shortens the distance for far field zone.

antenna systems the far field distance could be slightly superior to 1 meter[86]. In any case by regulations, in indoor WLAN systems the maximum antenna gain limit is 6 dBi[87].

The signal model is implemented by ***SpectrumSignalParameters ()*** class which is a generic and independent of the radiocommunication technology and requires a domain of frequency bands included in the ***SpectrumModel ()*** class, its codomain values that are included in the ***Spectrumvalue ()*** class (serves to define the power spectral density, frequency dependant losses and Wi-Fi masks[88]) and the antenna class. The physical channel is implemented through the ***Wi-fiSpectrumValueHelper ()*** helper class.

In physical layer the main set of classes are those related with Wi-Fi features. It is important to highlight the spectrum properties and antenna features. For the definition of the antenna class, it is important considers that the radiator element in a Wi-Fi environment could be either a single monopole or a complex array of compounds antennas with reflector and directors elements.

Commercially are available Wi-Fi devices with up to eight antennas[89]; some of them detachables for increasing the range of gain through external highly directive antennas. For example: Yagi-Uda compound antenna, paraboloidal reflector compound antenna, corner reflector antenna and even aperture antennas. NS-3 do not support beamforming

[86] For example for a indoor monopole 5dBi antenna: See:(Tp-Link., 2019).

[87] See FCC CFR 47 15E (15-407) 6 dBi antenna limit for indoor Access point.

[88] Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/docs/doxygen/classns3_1_1_spectrum_value.html. Nov 1 2019

[89] For example the IEEE 802.11ac based Commscope Ruckus Access Point R730. For 5 GHz has 4 omnidirectional antennas and 4 adaptive antennas. See: (“Ruckus R730 Data Sheet,” 2019)

or space diversity, then the results of simulations has to be interpreted as SISO configurations.

Given the amount of options for the radiating elements a neutral antenna is preferred for analysis; then it will be used the ideal isotropic radiator, which has a three-dimensional spherical pattern and is related with real antennas through the EIRP[90] function. In addition for the Friis propagation model, the isotropic radiation pattern is the natural assumption. The attributes for this entity are included in the ***IsotropicAntennaModel ()*** class[91].

Once the physical media entities has been defined, the next step is to create the data link layer entities. In NS-3 for creating a functional Wi-Fi node it is better to use Wi-fi in-build net devices and models. The wireless media has to be managed through CSMA/CA functionalities and when the messages are long as is required in an energy delivery protocol, the use of RTS/CTS techniques are mandatory[92].

These primitives are performed by ***MacLow ()*** class, NS-3 currently does not support RTS/CTS/ACK primitives in HT mode, however the energy delivery is performed once the transactions for establish the channels are concluded. The DCF algorithm is performed by ***DcfManager ()*** class. The A-MSDU function is realized by ***EdcaTxopN ()*** class. There are another classes associated with the process of management of the frames detailed in the annexes.

Then when the media for the communication channels has been accessed and reserved, it is simulated the process to send the data frames in a IEEE 802.11n format with a

[90] EIRP: Comparative effective radiated power from a Isotropic radiator

[91] Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/doxygen/classns3_1_1_isotropic_antenna_model.html. Nov 1 2019

[92](Tanenbaum, Andrew S., 2011). P.263

physical layer OFDM transmission of groups of symbols clusters. For controlling the rate adaptation is chosen the Minstrel (Mcgregor, A., & Smithies, 2010) because is a well known algorithm[93], it is reported to work well with TCP (Khademi, N., Welzl, M., & Gjessing, 2012), additionally is an algorithm that performs well in presence of interference and its problem reported to the optimization of data rate when the quality of channel is deteriorated (D. Xia, n.d.) is secondary, given the fact that in the energy delivery have priority the lowest data rate. Minstrel algorithm is deployed by ***MinstrelHtWifiManager ()*** class.

For establish a data communications without access points or infrastructure components the incumbent subset is the ***AdHocWifiMac ()*** class. In the data link layer and in MAC sublayer the attributes for configure the customized energy requirements are found in ***RegularWifiMac ()*** class.

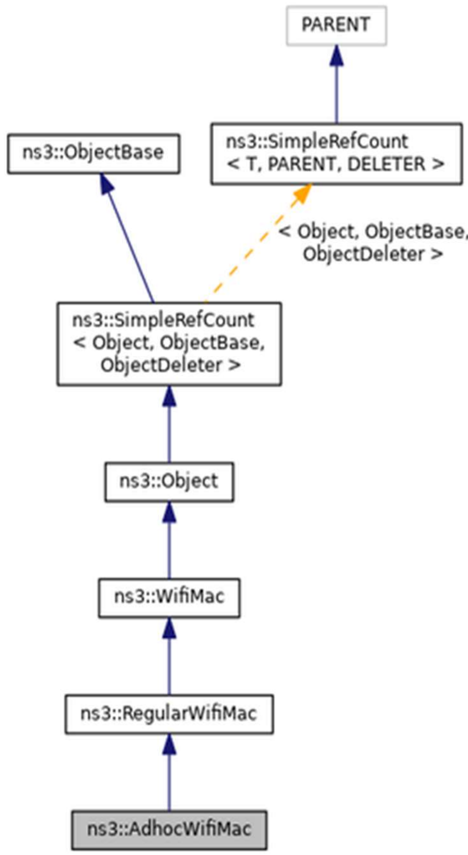
The following is the inheritance diagram for ad-hoc Wi-fi class[94].

[93] Minstrel has several implementations over GNU/Linux and its authors claim that is one of the best control rate algorithms. (Berg, 2019)

[94] Conventions: A filled gray box represents the class for which the graph is generated. A box with a black border denotes a documented class. A dark blue arrow is used to visualize a public inheritance relation between two classes. A yellow dashed arrow denotes a relation between a template instance and the template class it was instantiated from. A box with a gray border denotes an undocumented class.

Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/docs/doxygen/graph_legend.html. Nov 1 2019

Figure 5-2: Inheritance diagram for default ns3::AdhocWifiMac[95]



This class do not generate beacons or association, then these functionalities must be performed from top layers. The HT feature is supported from ***RegularWifiMac ()*** class; the data rate managing is performed by ***ConstantRateWifiManager ()*** class because NS-3 currently does not support adaptive data rates. Given the fact that for energy delivery are required low data rates there is no impact of this characteristic of the simulator.

[95] Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/docs/doxygen/classns3_1_1_adhoc_wifi_mac.html. Nov 1 2019.

Once the IBSS stations have negotiated the connection is determined the IP addressing for the link and begins the three way TCP handshake (as a matter of fact, this connection is an ad-hoc link establishment out of scope of the simulation, because when the simulation runs the link is preexistent). The connection by means of TCP is present work is performed by ***TcpSocketFactory () class*** which enables the creation of TCP sockets through the ***CreateSocket () function***.

The NS-3 implementation of TCP allows the customization of many protocol variables, among these, the use of several alternatives for congestion control for wireless networks. It has been developed the Westwood+ algorithm (Gangadhar, S., Nguyen, T. A. N., Umapathi, G., & Sterbenz, J. P. (2013, 2013)) for environments where there is a significative packet loss, bit errors and performance degradation.

In practice, the datagram timeout and ACK repeated are considered also as congestion, and TCP avoids the congestion mainly through adjust of the congestion window, Westwood estimates the round-trip delay time RTT for determine the effective bandwidth and the congestion window. The algorithm is a modification of Reno algorithm which is available through the ***Westwood ()*** class that inherits properties of the Reno algorithm and the (+) option is an adjustable parameter[96] in the code of the algorithm.

The available variables of TCP are not developed for energy transfer, their focus is the optimization or maximization of the throughput. There is needed further study for determine which of the existing variants improves the energy delivery rate and develop a new congestion control algorithm for energy delivery (if TCP is selected for the energy transmission). Either Westwood, Westwood+ and Reno software are available in the kernel of GNU/Linux operating system for further energy delivery testing.

[96] See WESTWOODPLUS Protocol Type. Nsnam. University of Washington. Retrieved from: https://www.nsnam.org/docs/doxygen/tcp-westwood_8h_source.html#l00087. Nov 1 2019

The data is generated from NS-3 traffic generator ***BulkSendApplication () class.***

The code of the energy application is based on the NS-3 example codes, installed by default in examples file, the following are the source code scripts used as reference and modified:

1. *tcp-bulk-send.cc*
2. *wifi-adhoc.cc*
3. *80211n-mimo.cc*
4. *wifi-TCP.cc*
5. *energy-model-with-harvesting-example.cc*

The complete code and comments it is related in the annexes (Annex C) of the present document. The following is the list of parameters customized in the existing libraries for the transmission oriented protocol, the summary of these simulation parameters is:

Table 5-1: Summary of the parameters of the simulation

ID	Parameter	Value
1	Standard	IEEE 802.11n
2	Band	36 UNII-1
3	Frequency	5.18 GHz
4	MIMO	1:1
5	Mode	IBSS
6	MCS	7

ID	Parameter	Value
7	Diversity	None. OFDM
8	Antenna model	Isotropic
9	Distance	1 m
10	TCP Variant	New Reno
11	TCP ports	9, 80
12	Payload	Variable
13	Simulation Time	10 seg.

Source name: own-elaboration

The simulation scenario it is summarized as a two nodes IEEE 802.11n linked by an IBSS ad-hoc network, transmitting in UNII-1 Band 36, with a separation of 1 meter. It is not considered specific environment conditions with exception of the far field zone considerations. The two stations Exchange control frames and then ocurrs a TCP data connection. The energy model it is implemented through a predefined energy conditions in the stations and it is reported the estimated amount of energy received througth the energy frames. The purpose of the simulation it is the execution of a communication protocol for energy delivery.

In the following table (5-2) are presented six scenarios (s1, s2, s3, s4, s5, s6) of simulation, in each one it is changed the payload size of TCP packets. There is a high variation of the power harvester levels, so there is not an apparent dependence between the payload size and the energy harvested. The distance of the link it was constant and equal to 1m.

Table 5-2: Results of a harvested power (W) simulation example

Time (s)	s1	s2	s3	s4	s5	s6	Average
0	0,0879023						0,0879023
1	0,0900605			0,0879023	0,0879023	0,0879023	0,08844185
2	0,0276296	0,0276296	0,0276296	0,0900605			0,043237325
3	0,060987	0,060987	0,060987				0,060987
4	0,00113641	0,00113641	0,00113641	0,0276296		0,0900605	0,024219866
5	0,0593717	0,0593717	0,0593717				0,0593717
6	0,0981622	0,0981622	0,0981622	0,060987	0,0276296		0,07662064
7	0,0297473	0,0297473	0,0297473			0,0276296	0,029217875
8	0,0784169	0,0784169	0,0784169	0,00113641			0,059096778
9	0,0431852	0,0431852	0,0431852		0,0728403		0,05801275
Average	**0,057659**	**0,049829**	**0,049829**	**0,053543**	**0,066810**	**0,06853**	**0,0559290**

Source name: own-elaboration

Table 5-3: Results of a remaining energy (J) simulation example

Time (s)	s1	s2	s3	s4	s5	s6	Average
0	0,17948			0,26890	0,268902	0,268902	0,233133
1	0,14074	0,14057	0,14057	0,17196	0,1638	0,1638	0,151529
2	0,17867	0,178677	0,178677				0,178677
3	0,17981	0,179814	0,179814	0,23538		0,360242	0,227012
4	0,23918	0,239185	0,239185				0,239185
5	0,33734	0,337347	0,337347	0,35735	0,35307		0,344493
6	0,36709	0,367095	0,367095			0,470761	0,393011
7	0,44551	0,445512	0,445512	0,35962			0,4240407
8	0,48869	0,488697	0,488697		0,4669433		0,4778201
9	0,26152	0,279718	0,2797185	0,26086	0,3644336	0,315926	0,28727121
Average	**0,261525**	**0,279718556**	**0,279718556**	**0,260864**	**0,36443367**	**0,3159263**	**0,2872712**

Source name: own-elaboration

In the previous table (5-3) are presented six scenarios (s1, s2, s3, s4, s5, s6) of simulation, in each one it is changed the payload size. There are a relatively constant set of values of the remaining energy levels so there is not a clear dependence between the payload size and the energy harvested. The distance of the link it was constant and equal to 1m.

With other conditions unchanged, the direct dependence of the level of energy in function of the time of the transmission was the most important hypotheses, but the results showed no consistent relation between them. Complementarily it was found that in slightly different scenarios, frequently the results were invariant. In other cases changing several input parameters, do not produces an appreciable change in the outputs of the program. These were a basic control points to check the fiability of the simulation altought it were unsuccesfull.

It was also desirable to extract an indicator related with a factor of energy associated to the relation between the number of control frames and the number of dataframes. In the same way it would was desirable to evaluate another variables and dependences of the communication process in another simulations scenarios, like the determination of the function of dependence with the link distance, (when the link is used with energy transmission considerations) to confirm as was said and showed previously (in the table 3.2,) with respect of the signal estimations made with an isotropic propagation model. This basic scenarios and tests are mentioned only as an example and the beginning of future work. (For doing preferably with tailored hardware and software).

Althought NS-3 is a very complete software in so many fields of telecommunications and improves year after year with impressive new features, also it is important to say that it is a command-line object-oriented-programming simulator and that for its use, both tools and skills of programmer are higly recommendable. In any case, any weakness it is an opportunity for further work to develop specialized libraries for NS-3 with energy capabilities from physical layer to transport layer, to take advantage of their rich set of telecommunications protocols.

On the other hand exists an active NS-3 community and the information in scientific literature and forums are increasingly growing also. The IEEE 802.11 is a huge standard and only the more relevant part has been implemented in NS-3 libraries. From the information available in NS-3 web site in this moment it is no clear which will be the timeline in relation with the develop or implementation of new specific Wi-Fi features, because sometimes the releases it appears with new functionalities but in others the releases do not contains new Wi-Fi or spectrum libraries. However very often at the end of the year and after several releases usually NS-3 has made an important progress in capabilities in the Wi-Fi libraries.

It is important to indicate for the reasons exposed in the document, that currently it is not posible to verify power and energy levels from a commercial device IEEE 802.11n HT ad-hoc as energy source, then one purpose of this work it is to highlight the most important aspects in the formulation of an energy protocol in this specific scope. However in the author’s opinion this analysis are a step in the direction of the future delivery of wireless energy services. Probably the next step could be to formulate an application that integrates the requirements of a energy transfer business model with the best of current protocols (for energy delivery). In a near future someone has to give the jump to build the hardware with new capabilities oriented to energy transmission.

Eventually will be explored another RF bands and will be tested the limits of human exposure for this specific application, giving as a result a physical layer capable of higher density of energy and improved distances. Is sure that in parallel will arrive an improved set of protocols ready to operate in lower layers of the OSI model.

6. Conclusions and recommendations

6.1 Conclusions

The current developments in the wireless technologies were not conceived for energy transmission purposes and the focus on energy transmission requires in my humble opinion a modification in the design paradigms of the telecommunications devices. It is needed a shift from the parameters of high throughput to a new focus on to maximize the efficiency of the energy management and delivery. With the current state of the art it is uncertain whether a system with high performance data rates could be also good in energy transmission. It is required further work in new devices with this orientation.

The losses associated with energy conversion processes are important in any wireless energy transfer, however the stage where it is more important to have high efficiencies is the part of the radiating processes. Given the dispersive nature of the wireless systems, the most efficient the physical layer, the most efficient the system by far.

In ad-hoc networks the network layer is not always needed and depending the protocol, some basic routing tasks are based on physical addressing and in link layer capabilities of the nodes. Given the fact that ideally the energy transfer operations it ocurrs in the lower parts of the protocol stack, then it is desirable that the protocol of energy transfer resides mainly into the link layer during the energy transactions.

The stack of internet protocols over IEEE 802.11n standard contains several repetitive operations focused in to guaranties the integrity and security of information. In the different layers it exists sucesive checks of consistence of data. The processing of the data pass first by one protocol (oriented to connection) followed of another protocol (oriented to best effort), followed by another protocol to establish a connection in a logical level and so one. In a energy transfer protocol some of these operations are undesirables, because the objective is to make an effective transfer of energy, as durable as much as possible, even with interruptions, errors or communications at low speeds, it is also important to reduce the spend of energy used in the successive data verifications.

In order to build energy transfer applications in the far field region on a radiator, with the devices currently available it will be needed to take control of the radio functionalities. For this, it will be required to develop new drivers and enable the operating system capabilities related. This tools are usually developed by manufacturers and are carefully controlled by them. Every feature and every release of hardware and software is weighted on forecasts of the market share. However, it is possible, that driven by the market forces in some point, some manufacturers eventually allow the access, provide the information, provide the tools and enable the management of the hardware through new open API standards and functionalities.

When the research process for build this document began several years ago, it seemed that the technology of wireless energy transfer as is proposed here, was very near to appear any day. Currently is clear to me that there are many challenges for addressing and new technologies to develop in order to have an energy transfer efficient system. Then it is possible that these technologies take some years more before arrives. One of the most importants constraints is the care of health and the security considerations for persons in presence of field with high energy densities.

In a near future it will be developed an IT security theory for preventing energy attacks, once they begin to happen. This is a very interesting topic, not explored on present work and with mmore variables than presented in another energetic networks from real world.

6.2 Recommendations

Real experiments are needed to determine the critical variables for improvement of the energy transfer processes. Each manufacturer has its own designs and its special implementation of the wireless standards, then frequently it is not possible to know how was built a specific component or device and it requires to test with several devices and different models of the same manufacturer, and later do the same process with another manufacturer devices. It is a lot of work to build these testbeds but currently it the only way to understand the strengths and weaknesses of every type of devices.

It is interesting to determine if a specific sequence of data in the frames of the underlying communication process that supports the energy transfer it has most capacity of deliver energy than other data sequences. The test of this experience is recommended as future work. This kind of experiments are too hard to evaluate from analytical techniques or by simulating tests. However is easier to deploy it in a basic wireless probe.

It is important to say that NS-3 is a discrete event simulator in constant evolution, and one point that could be reinforced is its compiler, specifically in its module of errors, because it is not always easy to track warnings or errors. Another point of improvement is the compatibility of code between updated different versions. The code included in the present work does not run immediately in posterior versions to 3.26 release.

Simulation it is a good way to improve and develop logical procedures, it is required that the simulations tools have precise models of the electromagnetic interactions in the air channel and in the RF processing stages. The NS-3 wireless channels and propagation models are good points of departure for understand the communications processes. For energy delivery applications it must be developed specific libraries and procedures based on detailed models of energy density, of MIMO processing and beamforming techniques. In any case the results it must be compared with real experimentation for establish similarities, for identifying test points, the critical factors and the best interpolation values.

A. Annex: NS-3 classes

The following are the public member functions for *AdhocWifiMac ()* class:

Table 6-1: NS-3 Ad-hoc Wi-fi class public member functions

ID	DESCRIPTION
1	void Enqueue (Ptr< const Packet > packet, Mac48Address to)
2	void SetAddress (Mac48Address address)
3	void SetLinkUpCallback (Callback< void > linkUp)

Source name: own-elaboration

The following are the public member functions for RegularWifiMac () class:

Table 6-2: NS-3 Regular Wi-fi class public member functions

ID	DESCRIPTION
1	virtual void Enqueue (Ptr< const Packet > packet, Mac48Address to, Mac48Address from)
2	Time GetAckTimeout (void) const
3	Mac48Address GetAddress (void) const
4	Time GetBasicBlockAckTimeout (void) const
5	Mac48Address GetBssid (void) const

ID	DESCRIPTION
6	Time GetCompressedBlockAckTimeout (void) const
7	Time GetCtsTimeout (void) const
8	Time GetEifsNoDifs (void) const
9	ExtendedCapabilities GetExtendedCapabilities (void) const
10	HeCapabilities GetHeCapabilities (void) const
11	HtCapabilities GetHtCapabilities (void) const
12	Time GetPifs (void) const
13	Time GetRifs (void) const
14	bool GetRifsSupported (void) const
15	bool GetShortSlotTimeSupported (void) const
16	Time GetSifs (void) const
17	Time GetSlot (void) const
18	Ssid GetSsid (void) const
19	VhtCapabilities GetVhtCapabilities (void) const
20	Ptr<WifiPhy> GetWifiPhy (void) const
21	Ptr<WifiRemoteStationManager> GetWifiRemoteStationManager (void) const

ID	DESCRIPTION	
22	void	ResetWifiPhy (void)
23	void	SetAckTimeout (Time ackTimeout)
24	void	SetAddress (Mac48Address address)
25	void	SetBasicBlockAckTimeout (Time blockAckTimeout)
26	void	SetBssid (Mac48Address bssid)
27	void	SetCompressedBlockAckTimeout (Time blockAckTimeout)
28	void	SetCtsTimeout (Time ctsTimeout)
29	void	SetCtsToSelfSupported (bool enable)
30	void	SetEifsNoDifs (Time eifsNoDifs)
31	void	SetForwardUpCallback (ForwardUpCallback upCallback)
32	void	SetLinkDownCallback (Callback< void > linkDown)
33	void	SetLinkUpCallback (Callback< void > linkUp)
34	void	SetPifs (Time pifs)
35	void	SetPromisc (void)
36	void	SetRifs (Time rifs)
37	void	SetRifsSupported (bool enable)

ID	DESCRIPTION
38	void SetShortSlotTimeSupported (bool enable)
39	void SetSifs (Time sifs)
40	void SetSlot (Time slotTime)
41	void SetSsid (Ssid ssid)
42	virtual void SetWifiPhy (const Ptr< WifiPhy > phy)
43	virtual void SetWifiRemoteStationManager(const Ptr<WifiRemoteStationManager> stationManager)
44	virtual bool SupportsSendFrom (void) const

Source name: own-elaboration

The following are the public member functions for AdhocWifiMac () class:

Table 6-3: NS-3 Wi-fi MAC class public member functions

ID	DESCRIPTION
1	void ConfigureStandard (WifiPhyStandard standard)
2	Ptr< HeConfiguration > GetHeConfiguration (void) const
3	Ptr< HtConfiguration > GetHtConfiguration (void) const
4	Ptr< VhtConfiguration > GetVhtConfiguration (void) const
5	void NotifyPromiscRx (Ptr< const Packet > packet)

6	void NotifyRx (Ptr< const Packet > packet)
7	void NotifyRxDrop (Ptr< const Packet > packet)
8	void NotifyTx (Ptr< const Packet > packet)
9	void NotifyTxDrop (Ptr< const Packet > packet)
10	void SetDevice (const Ptr< NetDevice > device)
11	virtual void SetForwardUpCallback(Callback<void,Ptr<Packet>,Mac48Address,Mac48Address>upCallback)=0
12	void SetMaxPropagationDelay (Time delay)

Source name: own-elaboration

B. Annex: 5 GHz IEEE 802.11 bands[97]

Chosen bands for WPT[98]:

36 (5180 MHz)

48 (5240 MHz)

44 (5220 MHz)

40 (5200 MHz)

Table 6-4: 5 GHz channels available by country

802.11 5 GHz Channels Available by Country													
Channel	Center Frequency (MHz)	U.S.	Europe	Japan		Singapore	China	Israel	Korea	Turkey	Australia	South Africa	Brazil
		40/20 MHz	40/20 MHz	40/20 MHz	10 MHz	40/20 MHz	20 MHz	20 MHz	20 MHz	40/20 MHz	40/20 MHz	40/20 MHz	40/20 MHz
36	5180	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
38	5190	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
40	5200	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
42	5210	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
44	5220	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
46	5230	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
48	5240	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
52	5260	DFS	Indoors/DFS/ TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
56	5280	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
60	5300	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
64	5320	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors

[97] Source: Tektronix. Wi-Fi: Overview of the 802.11 Physical Layer and Transmitter Measurements. Retrieved from //public.cnrood.com/public/docs/WiFi_Physical_Layer_and_Transm_Meas.pdf pp.16.

[98] Source: Adapted from Tektronix. Wi-Fi: Overview of the 802.11 Physical Layer and Transmitter Measurements. Retrieved from //public.cnrood.com/public/docs/WiFi_Physical_Layer_and_Transm_Meas.pdf pp.16.

802.11 5 GHz Channels Available by Country													
Channel	Center Frequency (MHz)	U.S.	Europe	Japan		Singapore	China	Israel	Korea	Turkey	Australia	South Africa	Brazil
		40/20 MHz	40/20 MHz	40/20 MHz	10 MHz	40/20 MHz	20 MHz	20 MHz	20 MHz	40/20 MHz	40/20 MHz	40/20 MHz	40/20 MHz
183	4915	No	No	No	Yes	No	No	No	No	No	No	No	No
184	4920	No	No	Yes	Yes	No	No	No	No	No	No	No	No
185	4925	No	No	No	Yes	No	No	No	No	No	No	No	No
187	4935	No	No	No	Yes	No	No	No	No	No	No	No	No
188	4940	No	No	Yes	Yes	No	No	No	No	No	No	No	No
189	4945	No	No	No	Yes	No	No	No	No	No	No	No	No
192	4960	No	No	Yes	No	No	No	No	No	No	No	No	No
196	4980	No	No	Yes	No	No	No	No	No	No	No	No	No
7	5035	No	No	No	Yes	No	No	No	No	No	No	No	No
8	5040	No	No	No	Yes	No	No	No	No	No	No	No	No
9	5045	No	No	No	Yes	No	No	No	No	No	No	No	No
11	5055	No	No	No	Yes	No	No	No	No	No	No	No	No
12	5060	No	No	No	No	No	No	No	No	No	No	No	No
16	5080	No	No	No	No	No	No	No	No	No	No	No	No
34	5170	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
36	5180	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
38	5190	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
40	5200	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
42	5210	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
44	5220	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
46	5230	No	No	client only	No	Yes	No	Yes	Yes	Indoors	No	Indoors	Indoors
48	5240	Yes	Indoors	Yes	No	Yes	Yes	Yes	Yes	Indoors	Yes	Indoors	Indoors
52	5260	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
56	5280	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
60	5300	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
64	5320	DFS	Indoors/DFS/TPC	DFS/TPC	No	Yes	DFS/TPC	Yes	Yes	Indoors	DFS/TPC	Indoors	Indoors
100	5500	DFS	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	DFS/TPC	Yes	DFS
104	5520	DFS	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	DFS/TPC	Yes	DFS
108	5540	DFS	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	DFS/TPC	Yes	DFS
112	5560	DFS	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	DFS/TPC	Yes	DFS
116	5580	DFS	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	DFS/TPC	Yes	DFS
120	5600	No	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	No	Yes	DFS
124	5620	No	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	No	Yes	DFS
128	5640	No	DFS/TPC	DFS/TPC	No	No	No	No	Yes	DFS/TPC	No	Yes	DFS
132	5660	DFS	DFS/TPC	DFS/TPC	No	No	No	No	No	DFS/TPC	DFS/TPC	Yes	DFS
136	5680	DFS	DFS/TPC	DFS/TPC	No	No	No	No	No	DFS/TPC	DFS/TPC	Yes	DFS
140	5700	DFS	DFS/TPC	DFS/TPC	No	No	No	No	No	DFS/TPC	DFS/TPC	Yes	DFS
149	5745	Yes	SRD (25 mW)	No	No	Yes	Yes	No	Yes	No	Yes	No	Yes
153	5765	Yes	SRD (25 mW)	No	No	Yes	Yes	No	Yes	No	Yes	No	Yes
157	5785	Yes	SRD (25 mW)	No	No	Yes	Yes	No	Yes	No	Yes	No	Yes
161	5805	Yes	SRD (25 mW)	No	No	Yes	Yes	No	Yes	No	Yes	No	Yes
165	5825	Yes	SRD (25 mW)	No	No	Yes	Yes	No	Yes	No	Yes	No	Yes

Table 4. 802.11 5 GHz band available channels by country. Center Frequencies are given for 20 MHz or 40 MHz wide channels. 80 MHz channels are built with adjacent 40 MHz channels. 160 MHz channels are built with adjacent 80 MHz channels. Center Frequencies for 80 MHz and 160 MHz will differ from the ones provided here.

Dynamic Frequency Selection (DFS) - The objective is to achieve maximum system spectral efficiency in bit/s/Hz/site by means of frequency reuse, but still assure a certain grade of service by avoiding co channel interference and adjacent channel interference among nearby channels.

Indoors – Channel is allowed for indoor use only.

Client Only – Channel is allowed when used in a client mode only.

Transmit Power Control (TPC) - The intelligent selection of transmit power in a communication system to achieve good performance within the system.

Short Range Devices (SRD) – Regulation of the allowed power level of devices using this channel.

Yes/No – Each country defines which channels are allowed.

C. Annex: NS-3 program

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/* Based on energy-model-with-harvesting-example.cc
 * Author: Cristiano Tapparello <cristiano.tapparello@rochester.edu>
 * Copyright (c) 2014 Wireless Communications and Networking Group (WCNG),
 * University of Rochester, Rochester, NY, USA.
 *
 * Based on energy-model-with-harvesting-example.cc
 * Copyright (c) 2015, IMDEA Networks Institute
 * Author: Hany Assasa <hany.assasa@gmail.com>
 *
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * Modified an comments labeled as HJ by Hernán Jiménez <hdjimenezj@unal.edu.co>
 *
 *  * Network topology:
 *
 *   STA    STA (HJ: changed an AP for STA)
 *   *      *
 *   |      |
 *   n1     n2
 *
 * In this example, an HT station sends TCP packets.
 */


/**
 *
 * This example extends the energy model example by connecting a basic energy
```

```
 * harvester to the nodes.
 *
 * The example considers a simple communication link between a source and a
 * destination node, where the source node sends a packet to the destination
 * every 1 second. Each node is powered by a BasiEnergySource, which is recharged
 * by a BasicEnergyHarvester, and the WiFi radio consumes energy for the transmission/
 * reception of the packets.
 *
 * For the receiver node, the example prints the energy consumption of the WiFi radio,
 * the power harvested by the energy harvester and the residual energy in the
 * energy source.
 *
 * The nodes initial energy is set to 1.0 J, the transmission and reception entail a
 * current consumption of 0.0174 A and 0.0197 A, respectively (default values in
 * WifiRadioEnergyModel). The energy harvester provides an amount of power that varies
 * according to a random variable uniformly distributed in [0 0.1] W, and is updated
 * every 1 s. The energy source voltage is 3 V (default value in BasicEnergySource) and
 * the residual energy level is updated every 1 second (default value).
 *
 * The simulation start at time 0 and it is hard stopped at time 10 seconds. Given the
 * packet size and the distance between the nodes, each transmission lasts 0.0023s.
 * As a result, the destination node receives 10 messages.
 *
 */

#include "ns3/applications-module.h" //HJ
#include "ns3/point-to-point-module.h" //HJ
#include "ns3/netanim-module.h" // HJ
#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/mobility-module.h"
#include "ns3/config-store-module.h"
#include "ns3/wifi-module.h"
#include "ns3/energy-module.h"
#include "ns3/internet-module.h"
#include "ns3/command-line.h" //HJ
#include "ns3/config.h" //HJ
```

```
#include "ns3/string.h" //HJ
#include "ns3/pointer.h" //HJ
#include "ns3/log.h" //HJ
#include "ns3/yans-wifi-helper.h" //HJ
#include "ns3/ssid.h" //HJ
#include "ns3/mobility-helper.h" //HJ
#include "ns3/internet-stack-helper.h" //HJ
#include "ns3/ipv4-address-helper.h" //HJ
#include "ns3/on-off-helper.h" //HJ
#include "ns3/yans-wifi-channel.h" //HJ
#include "ns3/wifi-net-device.h" //HJ
#include "ns3/wifi-mac.h" //HJ
#include "ns3/packet-sink-helper.h" //HJ
#include "ns3/packet-sink.h" //HJ
/* #include "ns3/ht-configuration.h" //HJ */


#include <iostream>
#include <fstream>
#include <vector>
#include <string>

using namespace ns3;

Ptr<PacketSink> sink;                       /* Pointer to the packet sink application -----  HJ From adhoc-tcp-anim-v2*/
uint64_t lastTotalRx = 0;                   /* The value of the last total received bytes --- HJ From adhoc-tcp-anim-v2*/

void /* ---HJ From adhoc-tcp-anim-v2 */
CalculateThroughput () /*  ---HJ From adhoc-tcp-anim-v2 */
{ /* --HJ From adhoc-tcp-anim-v2 */
  Time now = Simulator::Now ();                                   /* Return the simulator's virtual time. ---HJ From adhoc-tcp-anim-v2 */
  double cur = (sink->GetTotalRx() - lastTotalRx) * (double) 8/1e5;     /* Convert Application RX Packets to MBits. ---HJ From adhoc-tcp-anim-v2 */
```

```
  std::cout << now.GetSeconds () << "s: \t" << cur << " Mbit/s" << std::endl; /*  ---HJ From adhoc-tcp-anim-v2 */
  lastTotalRx = sink->GetTotalRx (); /*  ---HJ From adhoc-tcp-anim-v2 */
  Simulator::Schedule (MilliSeconds (100), &CalculateThroughput); /*  ---HJ From adhoc-tcp-anim-v2 */
}

NS_LOG_COMPONENT_DEFINE ("EnergyWithHarvestingExample");

struct Parameters //HJ
{ //HJ
"	uint32_t payloadSize; //HJ"
"	double simulationTime; //HJ"
}; //HJ

static inline std::string
PrintReceivedPacket (Address& from)
{
  InetSocketAddress iaddr = InetSocketAddress::ConvertFrom (from);

  std::ostringstream oss;
  oss << "--\nReceived one packet! Socket: " << iaddr.GetIpv4 ()
      << " port: " << iaddr.GetPort ()
      << " at time = " << Simulator::Now ().GetSeconds ()
      << "\n--";

  return oss.str ();
}

/**
 * \param socket Pointer to socket.
 *
 * Packet receiving sink.
 */
void
ReceivePacket (Ptr<Socket> socket)
{
```

```
  Ptr<Packet> packet;
  Address from;
"  while ((packet = socket->RecvFrom (from)))    "
    {
      if (packet->GetSize () > 0)
        {
          NS_LOG_UNCOND (PrintReceivedPacket (from));
        }
    }
}

/**
 * \param socket Pointer to socket.
 * \param pktSize Packet size.
 * \param n Pointer to node.
 * \param pktCount Number of packets to generate.
 * \param pktInterval Packet sending interval.
 *
 * Traffic generator.
 */
static void
GenerateTraffic (Ptr<Socket> socket, uint32_t pktSize, Ptr<Node> n,
                 uint32_t pktCount, Time pktInterval)
{
  if (pktCount > 0)
    {
      socket->Send (Create<Packet> (pktSize));
      Simulator::Schedule (pktInterval, &GenerateTraffic, socket, pktSize, n,
                           pktCount - 1, pktInterval);
    }
  else
    {
      socket->Close ();
    }
}
```

```
/// Trace function for remaining energy at node.
void
RemainingEnergy (double oldValue, double remainingEnergy)
{
  std::cout << Simulator::Now ().GetSeconds ()
            << "s Current remaining energy = " << remainingEnergy << "J" << std::endl;
}

/// Trace function for total energy consumption at node.
void
TotalEnergy (double oldValue, double totalEnergy)
{
  std::cout << Simulator::Now ().GetSeconds ()
            << "s Total energy consumed by radio = " << totalEnergy << "J" << std::endl;
}

/// Trace function for the power harvested by the energy harvester.
void
HarvestedPower (double oldValue, double harvestedPower)
{
  std::cout << Simulator::Now ().GetSeconds ()
            << "s Current harvested power = " << harvestedPower << " W" << std::endl;
}

/// Trace function for the total energy harvested by the node.
void
TotalEnergyHarvested (double oldValue, double TotalEnergyHarvested)
{
  std::cout << Simulator::Now ().GetSeconds ()
            << "s Total energy harvested by harvester = "
            << TotalEnergyHarvested << " J" << std::endl;
}


int
main (int argc, char *argv[])
```

```
{
  /*
  LogComponentEnable ("EnergySource", LOG_LEVEL_DEBUG);
  LogComponentEnable ("BasicEnergySource", LOG_LEVEL_DEBUG);
  LogComponentEnable ("DeviceEnergyModel", LOG_LEVEL_DEBUG);
  LogComponentEnable ("WifiRadioEnergyModel", LOG_LEVEL_DEBUG);
  LogComponentEnable ("EnergyHarvester", LOG_LEVEL_DEBUG);
  LogComponentEnable ("BasicEnergyHarvester", LOG_LEVEL_DEBUG);
  */
  std::string phyMode ("DsssRate1Mbps");
  double Prss = -80;            // dBm
  uint32_t PpacketSize = 200;   // bytes
  bool verbose = false;
/*uint32_t Parameters params */
/*uint32_t payloadSize = 1472;                    Transport layer payload size in bytes. ---HJ From adhoc-tcp-anim-v2 */
std::string dataRate = "100Mbps";                  /* Application layer datarate. ---HJ From adhoc-tcp-anim-v2 */
std::string tcpVariant = "ns3::TcpWestwood";       /* TCP variant type. HJ: it was changed (first change) NEWRENO for WESTWOOD without noticeable effect */
std::string phyRate = "HtMcs7";                   /* Physical layer bitrate. HJ: Does not allow change it, transmissions deliver 0 mbps and finish with an error */
/* double simulationTime = 2;                      Simulation time in seconds. ---HJ From adhoc-tcp-anim-v2 */
/*  bool pcapTracing = false;                      PCAP Tracing is enabled or not. ---HJ From adhoc-tcp-anim-v2 */
  // simulation parameters
  uint32_t numPackets = 10000;  // number of packets to send
  double interval = 1;          // seconds
  double startTime = 0.0;       // seconds
```

```
  double distanceToRx = 1.0;  // meters
  /*
   * This is a magic number used to set the transmit power, based on other
   * configuration.
   */
  double offset = 81;

  // Energy Harvester variables
  double harvestingUpdateInterval = 1;  // seconds

  /* Command line argument parser setup. */

  CommandLine cmd;
  cmd.AddValue ("phyMode", "Wifi Phy mode", phyMode);
  cmd.AddValue ("Prss", "Intended primary RSS (dBm)", Prss);
  cmd.AddValue ("PpacketSize", "size of application packet sent", PpacketSize);
  cmd.AddValue ("numPackets", "Total number of packets to send", numPackets);
  cmd.AddValue ("startTime", "Simulation start time", startTime);
  cmd.AddValue ("distanceToRx", "X-Axis distance between nodes", distanceToRx);
  cmd.AddValue ("verbose", "Turn on all device log components", verbose);



/*  cmd.AddValue ("payloadSize", "Payload size in bytes", payloadSize); ---HJ From adhoc-tcp-anim-v2 */
  cmd.AddValue ("dataRate", "Application data ate", dataRate); /* HJ From adhoc-tcp-anim-v2 */
  cmd.AddValue ("tcpVariant", "Transport protocol to use: TcpTahoe, TcpReno, TcpNewReno, TcpWestwood, TcpWestwoodPlus ", tcpVariant); /* HJ From adhoc-tcp-anim-v2 */
  cmd.AddValue ("phyRate", "Physical layer bitrate", phyRate); /* HJ From adhoc-tcp-anim-v2 */
/*  cmd.AddValue ("simulationTime", "Simulation time in seconds", simulationTime); ---HJ From adhoc-tcp-anim-v2 */
/*  cmd.AddValue ("pcap", "Enable/disable PCAP Tracing", pcapTracing); ---HJ From adhoc-tcp-anim-v2 */
  cmd.Parse (argc, argv); /* HJ From adhoc-tcp-anim-v2 */
```

```

    // Convert to time object
    Time interPacketInterval = Seconds (interval);

    // disable fragmentation for frames below 2200 bytes
    Config::SetDefault ("ns3::WifiRemoteStationManager::FragmentationThreshold",
                        StringValue ("2200"));
    // turn off RTS/CTS for frames below 2200 bytes
    Config::SetDefault ("ns3::WifiRemoteStationManager::RtsCtsThreshold",
                        StringValue ("2200"));
    // Fix non-unicast data rate to be the same as that of unicast
    Config::SetDefault ("ns3::WifiRemoteStationManager::NonUnicastMode",
                        StringValue (phyMode));

    NodeContainer c;
    c.Create (2);    // create 2 nodes
    NodeContainer networkNodes;
    networkNodes.Add (c.Get (0));
    networkNodes.Add (c.Get (1));

    // The below set of helpers will help us to put together the wifi NICs we want
    WifiHelper wifi;
    if (verbose)
      {
        wifi.EnableLogComponents ();
      }
    wifi.SetStandard (WIFI_PHY_STANDARD_80211b);

    /** Wifi PHY **/
    /************************************************************************/
    YansWifiPhyHelper wifiPhy = YansWifiPhyHelper::Default ();
    wifiPhy.Set ("RxGain", DoubleValue (-10));
    wifiPhy.Set ("TxGain", DoubleValue (offset + Prss));
    wifiPhy.Set ("CcaMode1Threshold", DoubleValue (0.0));
    /************************************************************************/
```

```

/** wifi channel **/
YansWifiChannelHelper wifiChannel;
wifiChannel.SetPropagationDelay ("ns3::ConstantSpeedPropagationDelayModel");
wifiChannel.AddPropagationLoss ("ns3::FriisPropagationLossModel");
// create wifi channel
Ptr<YansWifiChannel> wifiChannelPtr = wifiChannel.Create ();
wifiPhy.SetChannel (wifiChannelPtr);

/** MAC layer **/
// Add a MAC and disable rate control
WifiMacHelper wifiMac;
wifi.SetRemoteStationManager ("ns3::ConstantRateWifiManager", "DataMode",
                              StringValue (phyMode), "ControlMode",
                              StringValue (phyMode));
// Set it to ad-hoc mode
wifiMac.SetType ("ns3::AdhocWifiMac");

/** install PHY + MAC **/
NetDeviceContainer devices = wifi.Install (wifiPhy, wifiMac, networkNodes);

/** mobility **/
MobilityHelper mobility;
Ptr<ListPositionAllocator> positionAlloc = CreateObject<ListPositionAllocator> ();
positionAlloc->Add (Vector (0.0, 0.0, 0.0));
positionAlloc->Add (Vector (2 * distanceToRx, 0.0, 0.0));
mobility.SetPositionAllocator (positionAlloc);
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
mobility.Install (c);

/** Energy Model **/
/***************************************************************************/
/* energy source */
BasicEnergySourceHelper basicSourceHelper;
// configure energy source
basicSourceHelper.Set ("BasicEnergySourceInitialEnergyJ", DoubleValue (1.0));
// install source
```

```
  EnergySourceContainer sources = basicSourceHelper.Install (c);
  /* device energy model */
  WifiRadioEnergyModelHelper radioEnergyHelper;
  // configure radio energy model
  radioEnergyHelper.Set ("TxCurrentA", DoubleValue (0.0174));
  radioEnergyHelper.Set ("RxCurrentA", DoubleValue (0.0197));
  // install device model
  DeviceEnergyModelContainer deviceModels = radioEnergyHelper.Install (devices, sources);

  /* energy harvester */
  BasicEnergyHarvesterHelper basicHarvesterHelper;
  // configure energy harvester
  basicHarvesterHelper.Set ("PeriodicHarvestedPowerUpdateInterval", TimeValue (Seconds (harvestingUpdateInterval)));
  basicHarvesterHelper.Set ("HarvestablePower", StringValue ("ns3::UniformRandomVariable[Min=0.0|Max=0.1]"));
  // install harvester on all energy sources
  EnergyHarvesterContainer harvesters = basicHarvesterHelper.Install (sources);
  /***************************************************************************/

  /** Internet stack **/
  InternetStackHelper internet;
  internet.Install (networkNodes);

  Ipv4AddressHelper ipv4;
  NS_LOG_INFO ("Assign IP Addresses.");
  ipv4.SetBase ("10.1.1.0", "255.255.255.0");
  Ipv4InterfaceContainer i = ipv4.Assign (devices);

  /* Populate routing table */
  Ipv4GlobalRoutingHelper::PopulateRoutingTables (); //HJ From adhoc-tcp-anim-v2

  TypeId tid = TypeId::LookupByName ("ns3::TcpSocketFactory"); //HJ From adhoc-tcp-anim-v2, changed UdpSocketFactory
  Ptr<Socket> recvSink = Socket::CreateSocket (networkNodes.Get (1), tid);  // node 1, Destination
```

```
  InetSocketAddress local = InetSocketAddress (Ipv4Address::GetAny (), 80);
  recvSink->Bind (local);
  recvSink->SetRecvCallback (MakeCallback (&ReceivePacket));

  /* Install TCP/UDP Transmitter on the station */
  /* OnOffHelper server ("ns3::TcpSocketFactory", (Ipv4Address::GetAny (), 9));*/
  /* server.SetAttribute ("PacketSize", UintegerValue (payloadSize));*/
  /* server.SetAttribute ("OnTime", StringValue ("ns3::ConstantRandomVariable[Constant=1]"));*/
  /* server.SetAttribute ("OffTime", StringValue ("ns3::ConstantRandomVariable[Constant=0]"));*/
  /* server.SetAttribute ("DataRate", DataRateValue (DataRate (dataRate)));*/
  /* ApplicationContainer serverApp = server.Install (networkNodes.Get (1));*/



  Ptr<Socket> source = Socket::CreateSocket (networkNodes.Get (0), tid);    // node 0, Source
  InetSocketAddress remote = InetSocketAddress (Ipv4Address::GetBroadcast (), 80);
  source->SetAllowBroadcast (true);
  source->Connect (remote);

  /* Install TCP Receiver on the source */
  PacketSinkHelper sinkHelper ("ns3::TcpSocketFactory", InetSocketAddress (Ipv4Address::GetBroadcast (), 80)); //HJ From adhoc-tcp-anim-v2 changing Getany ..9 by getbroadcast ..80
  ApplicationContainer sinkApp = sinkHelper.Install (networkNodes.Get(0)); //HJ From adhoc-tcp-anim-v2 changing Apnode for networkNodes.Get(0)
  /* sink = StaticCast<PacketSink> (sinkApp.Get (0)); //HJ From adhoc-tcp-anim-v2*/



  /** connect trace sources **/
  /***************************************************************************/
  // all traces are connected to node 1 (Destination)
  // energy source
  Ptr<BasicEnergySource> basicSourcePtr = DynamicCast<BasicEnergySource> (sources.Get (1));
  basicSourcePtr->TraceConnectWithoutContext ("RemainingEnergy", MakeCallback (&RemainingEnergy));
```

```
  // device energy model
  Ptr<DeviceEnergyModel> basicRadioModelPtr =
    basicSourcePtr->FindDeviceEnergyModels ("ns3::WifiRadioEnergyModel").Get (0);
  NS_ASSERT (basicRadioModelPtr != 0);
  basicRadioModelPtr->TraceConnectWithoutContext ("TotalEnergyConsumption", MakeCallback (&TotalEnergy));
  // energy harvester
  Ptr<BasicEnergyHarvester> basicHarvesterPtr = DynamicCast<BasicEnergyHarvester> (harvesters.Get (1));
  basicHarvesterPtr->TraceConnectWithoutContext ("HarvestedPower", MakeCallback (&HarvestedPower));
  basicHarvesterPtr->TraceConnectWithoutContext ("TotalEnergyHarvested", MakeCallback (&TotalEnergyHarvested));
  /***************************************************************************/

  /* Enable Traces HJ From adhoc-tcp-anim-v2 */
  /** if (pcapTracing)
    {
      wifiPhy.SetPcapDataLinkType (YansWifiPhyHelper::DLT_IEEE802_11_RADIO);
      wifiPhy.EnablePcap ("Receiver", networkNodes.Get (1));
      wifiPhy.EnablePcap ("Emitter", networkNodes.Get (0));
    } **/


  /* HJ: start animation */
"	//d.BoundingBox(0,0,10,10);"
"	AnimationInterface anim (""energy-model-with-harvesting-examplev2.xml"");"
"	anim.SetConstantPosition (networkNodes.Get(0), 20.0, 30.0, 0.0);"
"	anim.SetConstantPosition (networkNodes.Get(1), 30.0, 20.0, 0.0);"
"	anim.UpdateNodeSize (0, 0.1, 0.1);"
"	anim.UpdateNodeSize (1, 0.1, 0.1);"
"	anim.UpdateNodeDescription (0, ""Emitter"");"
"	anim.UpdateNodeDescription (1, ""Receiver"");"
"	//(!animFile.empty())"
"		//{"
"			//anim.SetOutputFile(animFile);"
"		//}"
```

```
"          //anim.StartAnimation();"


  /** simulation setup **/
  // start traffic
  Simulator::Schedule (Seconds (startTime), &GenerateTraffic, source, PpacketSize,
  networkNodes.Get (0), numPackets, interPacketInterval);

  Simulator::Stop (Seconds (10.0));
  Simulator::Run ();
  Simulator::Destroy ();

  return 0;

}
```

D. Annex: Example of simulation results

…'build' finished successfully (4.664s)

0s Current harvested power = 0.0879023 W

0.000570667s Total energy consumed by radio = 0.000467376J

0.000570667s Current remaining energy = 0.999583J

0.00287467s Total energy consumed by radio = 0.000603543J

0.00287467s Current remaining energy = 0.999649J

--

Received one packet! Socket: 10.1.1.1 port: 49153 at time = 0.00287467

--

1s Current harvested power = 0.0900605 W

1s Total energy harvested by harvester = 0.0900605 J

1s Current remaining energy = 0.272805J

1s Total energy consumed by radio = 0.81725J

1s Current remaining energy = 0.272805J

1.0023s Total energy consumed by radio = 0.817386J

1.0023s Current remaining energy = 0.272876J

--

Received one packet! Socket: 10.1.1.1 port: 49153 at time = 1.0023

--

2s Current harvested power = 0.0276296 W

2s Total energy harvested by harvester = 0.11769 J

2s Current remaining energy = 0J

2s Total energy consumed by radio = 1.6345J

3s Current harvested power = 0.060987 W

3s Total energy harvested by harvester = 0.178677 J

4s Current harvested power = 0.00113641 W

4s Total energy harvested by harvester = 0.179814 J

5s Current harvested power = 0.0593717 W

5s Total energy harvested by harvester = 0.239185 J

6s Current harvested power = 0.0981622 W

6s Total energy harvested by harvester = 0.337347 J

7s Current harvested power = 0.0297473 W

7s Total energy harvested by harvester = 0.367095 J

8s Current harvested power = 0.0784169 W

8s Total energy harvested by harvester = 0.445512 J

9s Current harvested power = 0.0431852 W

9s Total energy harvested by harvester = 0.488697 J

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