Energy Efficiency in Wireless Networking Protocols

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Abstract:

This article discusses the necessity of energy efficiency in wireless networking protocols, several energy efficiency measures usually applied in wireless networking and protocols implementing these measures according to their applications and environment.

Keywords:

Energy Efficiency, Wireless Networks, Wireless Networking Protocol, Active/Sleep mode, Directional Antenna, Cognitive Radio, Green Technology, Interference Management, Energy Harvesting.

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1.0 Introduction

With the fast development of wireless networking in the world, the energy efficiency of wireless networking protocols becomes a concern of many wireless networking stakeholders. They have interests on the energy efficiency in wireless networking protocols for various reasons such as design problem, green technology policy, cost and final user satisfaction [Jumira13].

There are many measures for saving the energy in wireless networks protocols. Some are focusing on saving the energy in different modes such as active/sleep modes. Some are concerned about reducing interference and achieving higher signal-noise ratio with the same transmission radio power. Some are concerned about increasing the speed according to the application and environment to save the time working under active modes.

Different wireless networks protocols take one or several energy efficiency measures to reduce the power consumption according to their payload, cover area, and the demand for energy. Therefore, the protocols integrate the energy efficiency characteristics into applications to achieve balances of power consumption between the energy efficiency and functions.

2.0 The importance of energy efficiency in wireless networking protocols

With all the talks about global warming, the governments, network device manufacturers, networks service providers and users are more concerned about energy efficiency of the wireless devices than before. The reasons for requiring the more energy efficiency in wireless are various, but most of them are worrying about design problem, the policy of green technology, saving the business cost, and final user satisfaction.

2.1 Solving Design problem

Most energy used by wireless devices eventually turns into heat. The more energy a device uses, the more heat it produces. Transistors usually work more reliably when they work under normal temperature. If they are overheated, they start malfunctioning or being totally destroyed. In order to decrease the temperature, we might need a large cooling system which is not realistic for the mobility of wireless devices. What is more, the cooling system might require more power to run which in turn cause more heat. Therefore, because of design problems of the wireless devices, we need wireless networks protocols to be more energy efficient [Wikipedia01].

2.2 Green Technology Policy

Nowadays, almost all governments in the world face the energy problem. The society is also concerned about environment problems such as green-house gas problem. If we use more energy, more greenhouse gas will be produced. For this reason, there are many compulsory or non-compulsory standards that require devices to be energy efficiency. In order to enter some countries' market, wireless networking manufacturers need to have their products certified for those compulsory standards. For non- compulsory standards, manufacturers might use them for marketing because more people are willing to buy products that harm the world less. Implementing energy efficiency wireless protocols in devices could reduce the use of energy thus might more easily have them passed those energy efficiency standard certifications [Jumira13] [Wikipedia02].

2.3 Reducing Cost

Base stations use a lot of energy to transmit or receive wireless signals. With the development of energy efficiency protocols, less heat will be produced by wireless devices in base stations. In the mean time, less energy would be needed in order to maintain the environment temperature of the base stations because less heat was produced by devices. The service provider might save some cost on electricity. Therefore, wireless service providers would welcome the energy efficiency wireless networking protocols.

2.4 Customer satisfaction

The users of wireless networking generally have a high expectation of mobility of wireless networking terminals. They are looking for light weight, long battery life wireless portable devices. On the one hand, new researches on battery technologies can expand the battery capacity. On the other hand, the energy efficiency protocols could save the power and expand the battery life.

From what is discussed above, the energy efficiency protocols are demanded by governments, manufacturers, service providers, societies and final users. It should not be surprised that most wireless networking protocols use various measures to make wireless devices run more efficiently.

3.0 Measures for energy efficiency wireless networking

In wireless networking protocols, there are several measures to make wireless network work more energy efficiency. Some of them are concerned on reducing the power consumption during different states, for example active/sleep mode; some of them are concerned about reducing interference of wireless transmission, so they can decrease the error rate and the needs to retransmit; some of them try to increase the transmission rate that could reduce the active work time, and some of them try to collect green energy which would decrease the power supply from other source. This paper will discuss these measures in detail in the following sections.

3.1 Active/Sleep modes

In most wireless networking applications especially in communication, we want our devices be able to receive some real time information. But during most time, we don't need the devices to work at full load. Therefore, the devices only need to transmit little data during sleep mode but might need to transmit large data during active mode. If protocols are able to change active/sleep modes under different transmission demands and use energy wisely, it could save a lot of energy because if a device works under sleep mode, it generally uses less energy than under active mode. During the sleep mode the device could turn off a lot of applications and only maintain some basic communications.

Before 802.11e was adopted, there is a power saving polling mechanism available in wireless network protocols. However, it does not have Scheduled Automatic Power Save Delivery (S-APSU) mode, thus the Access Point (AP) needs power save polling signals between AP and stations typically after each beacon which is similar to Unscheduled Automatic Power Save Delivery (U-APSU) in 802.11e. The poll signals would cause more traffic and more collisions. With the applications of S- APSD in 802.11e, AP only needs to start service with stations on predetermined time, therefore AP could reduce power consumption.

In Bluetooth protocol, there are more sleep modes than active/sleep modes because Bluetooth is more concerned about the battery life of peripheral devices. In Bluetooth protocol, there is a connected mode which is the same as active mode in other protocols.[Jain14] It has a 3 bit active member address, and be able to transmit both in synchronous and asynchronous connections. However, Bluetooth has three kinds of sleep modes. In Hold mode, the device keeps 3 bit active member address and communicates only in synchronous connection oriented but not asynchronous connection. In Sniff mode, the device does not have any communication but only listens to the master for every a fixed sniff interval. In Park mode, the device gives up its 3 bits active member address and get 8 bits park address, and wakes up and listens to beacons. By using different sleep modes in Bluetooth protocols, the device could be able to save more energy according to the communication demand. This is very helpful for energy efficiency and can have a longer battery life.

Tab 1: Different modes in Bluetooth

Modes	Address	Communication	Max sleep period
Connected	3 bits Active member address	Both synchronous and asynchronous	NA
Hold	3 bits Active member address	Only synchronous	500ms
Sniff	3 bits Active member address	Only listen after a fixed Sniff interval	50ms
Park	8 bits Park address	Only listen to beacon after a period	10s

By using different sleep modes in Bluetooth protocol, the device is able to save more energy according to the communication demand. This is very helpful for energy efficiency and thus the device can have a longer battery life.

3.2 Schedule management (beacon)

Schedule management can also save energy, because device does not need to send or listen to the signals continuously even in active mode. By using beacon, both AP and stations only need to send or receive the signals when the beacon turns to their schedule. Thus, it could decrease these the actual working time during the active mode.

For protocols that support beacons such as 802.11ad, 802.15.e/ZigBee, when stations work under beacon-enabled mode, they can support active/sleep modes and Guaranteed Time Slot (GTS) mechanism in the frame structure. (See Fig.1) [Tennina13] Therefore, it is possible to achieve power saving goal by achieving low duty cycle and GTS allocation if the payload is not large, for device only needs to send or listen to the beacon when it is its turn.

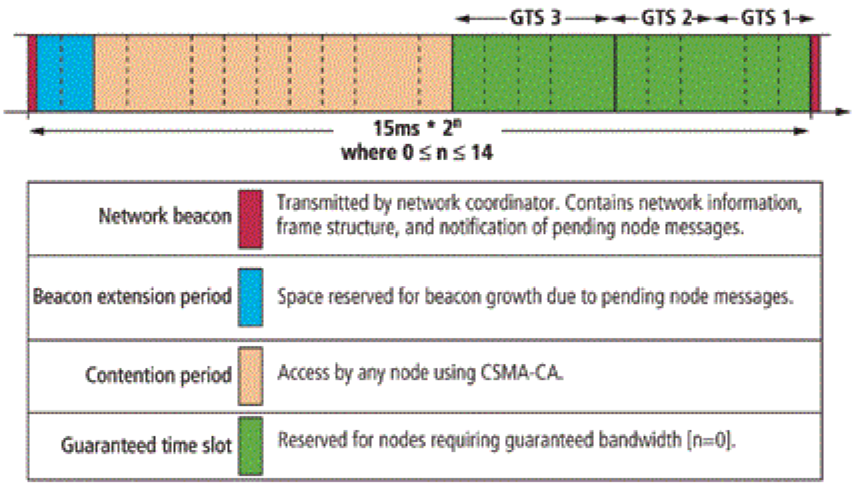

Fig.1 Frame Structure for 802.15.4 [ISA01]

For this reason, beacon could reduce power consumption further in active mode.

3.3 Directional Antenna

If we use isotropic antenna, the signal will be sent equally to all directions. This kind of transmission will require more transmission power than directional antenna. It is useful if a device wants to broadcast messages to multiple stations in different directions. However, in most applications, communications are unicast between two devices. For the same EIRP, by using directional antenna, we could save about at least half of transmission power than using the isotropic antenna. What's more, by using directional antenna, there is less interference between radios streams, the Signal-Noise ratio could also be increase. It could make the communication more reliable and thus less retransmission is required.

In device with Directional Radio, it is very important to find the best antenna direction and parameter quickly and rightly. Otherwise, the benefit of directional radio would be compromised by inefficiency overhead payload of antenna searching and non-optimal antenna direction or parameters. In 802.11ad protocol, a station uses a two-stage antenna training to find optimal antenna configuration with its recipient. The first stage is Sector Level Sweep (SLS) which sends training signals in all sectors and finds the optimal sector. The second stage is Beam Refinement Procedure stage which finds the optimal parameter in the optimal sector [Sai12]. Through this two-stage antenna training, the AP will be able to find the optimal sector and parameters for each recipient with few signal test data. There is also antenna alignment procedure which makes sure that the antenna is aligned with beam during the transmission. ECMA-387 uses almost the same antenna training and tracking procedure to make sure two stations having the optimal antenna configuration for communications between them [ECMA-387].

Hence, by using Directional Radio, wireless networking devices can reduce the power consumption while has the same SNR for transmitter and receiver.

3.4 Cognitive Radio

Interference causes the increase of noise of the using channels; it can decrease the signal-noise ratio of the transmission channel. In order to send signals in channel with strong interference, we might need to increase the transmission power which in return would cause the signal interfere other signals. So some protocols especially those have channel coexistence problems use Software Defined Antenna or Cognitive Radio to avoid using channels that might cause interferences.

Cognitive radio is able to sense available wireless channels and decide which channels to use according to programs and configurations. The cognitive radio can find the spectrums that are less interfered, can also bond several channels together to achieve high transmission speed. Because the cognitive use less interfered channels, it could save power in transmission to attain the same Signal-Noise ratio. What is more, by increasing the Signal-Noise ratio, it could achieve a higher speed, therefore, the device needs less time in active mode which could also save energy.

Both 802.22 and 802.11af use Television white space (TVWS) as their channels for communication. 802.11af is designed for wireless LAN for range up to 5 km while 802.22 is designed for wireless regional area networks for range up to 100 km. In order to avoid interference between these two protocols or between different devices that use the same protocols, both standards use cognitive radio technology to avoid interferences. In cognitive layer of both standards, they all have interfaces with geolocation device and TVWS database to get the spectrum resource information. 802.22 also has interface with spectrum sensors and has quiet periods for spectrum sensing [Lekomtcev12]. Because FCC does not require spectrum sensing for use of TVWS and these two standards is still under development, what kind of cognitive plane of the final versions of these two standards will use are still uncertain now. But it is very important that the protocols will have cognitive radios that are able to configure the radio to different TV channels to avoid interference by other devices.

So, although we do not know the final version of 802.22 and 802.11af, because they use the same TVWS channels resource, they need Cognitive radio to avoid interference and therefore more energy efficiency

3.5 Interference Management

Software Definition Radio / Cognitive Radio can solve the interference problem of device individually, but it might not solve the possible interference problems that the signals the device produced might affect other device. [Annapureddy11] So some protocols have the interference management to avoid interfere other devices.

Because both 802.22 and 802.11af use TVWS spectrum, they need a coexistence method to avoid interferences among stations using TVWS spectrum according to the location. The 802.19.1 proposal protocol is designed to solute the coexistence problem in TVWS. [Shellhammer10] The protocol uses discovery to find white space objects (WSO) that could affect each other's performance and then uses decision algorithm to classify different WSOs and allocates channels accordingly.

802.19.1 only solutes the coexistence problem, while 1900.4 optimizes the usage of spectrum resources in the whole area. It includes three use cases, which are dynamic spectrum assignment, dynamic spectrum sharing and distributed radio usage optimization. Through 1900.4, we could achieve optimizing the spectrum usage while satisfying each station requirement. (See Fig. 2) The Network Reconfiguration manager (NRM) could able to use the database to achieve the optimization of the channel resource and send the reconfigure commands to devices [NICT09]. 1900.4a is the amendment of 1900.4 in TVWS.

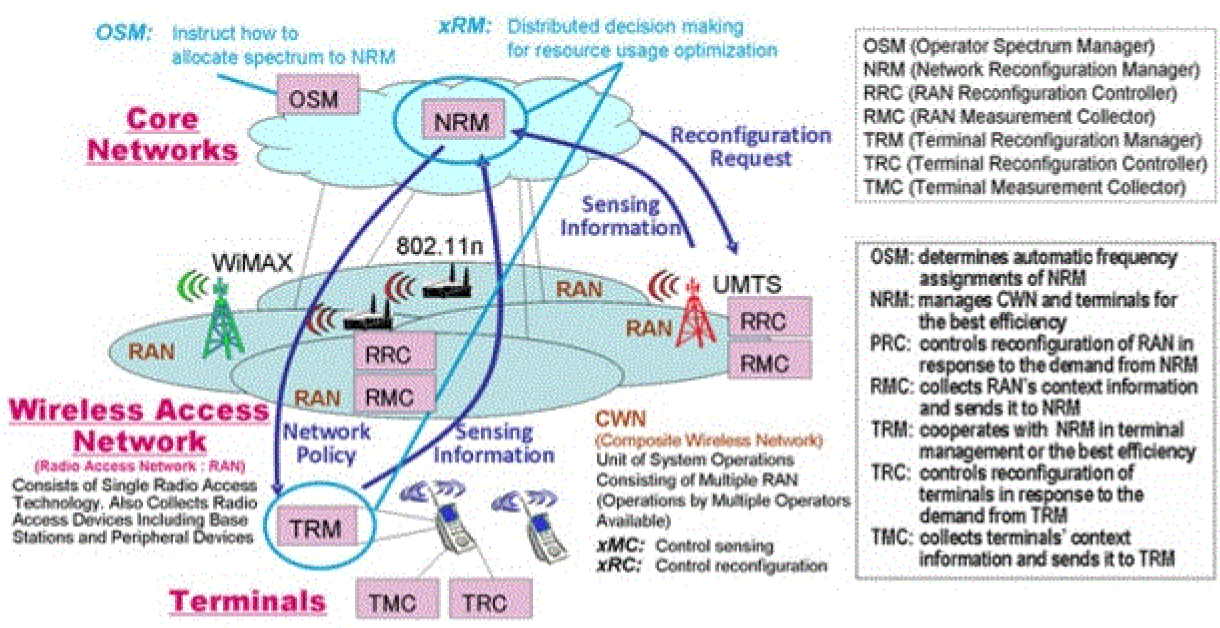

Fig.2 1900.4 system archtecture [NICT09]

Therefore, the whole coexistent TVWS would achieve the most energy efficiency with 1900.4a. The local wireless networking could achieve maximum energy efficiency via interference management.

3.6 High Transmission speed

The higher the speed, the less time a wireless device needs to spend on transferring the same payloads, a wireless device thus can have more time in sleep mode, or occupy less beacon time in transmission. In order to increase the energy efficiency, many protocols increase the transmission speed by modulation, channel bonding, and using higher frequency measures.

By using Orthogonal Frequency Division Multiplexing (OFDM) method, wireless protocols can divide a frequency band into a large number of small frequency bands; therefore each subcarrier has a smaller data rate which would increase symbol duration. Therefore, it can have less inter-symbol interference, thus can transfer in higher speed.

In modern wireless transmission, m-ary Quadrature Amplitude Modulation is widely use because it can transfer more bits in one symbol. It combines both the amplitude-shift key (ASK) and phase-shift key (PSK) technology to attain a high speed. [IEEE802.22-2011] Many wireless protocols apply QAM technology to achieve high speed, such as 802.11a, 802.11g, 802,11n and 802.22. In 802.22, the protocol uses different QAMs from 64-QAM, 16QAM and QPSK, to attain a balance between high speed and transmission error rates because of distance.(See Fig.3) [Pentz] In the proposal 802.22b there is 256-QAM which can increase symbol bit ratio from 6 bit/symbol of 64-QAM to 8 bit/symbol. [Zhao12]

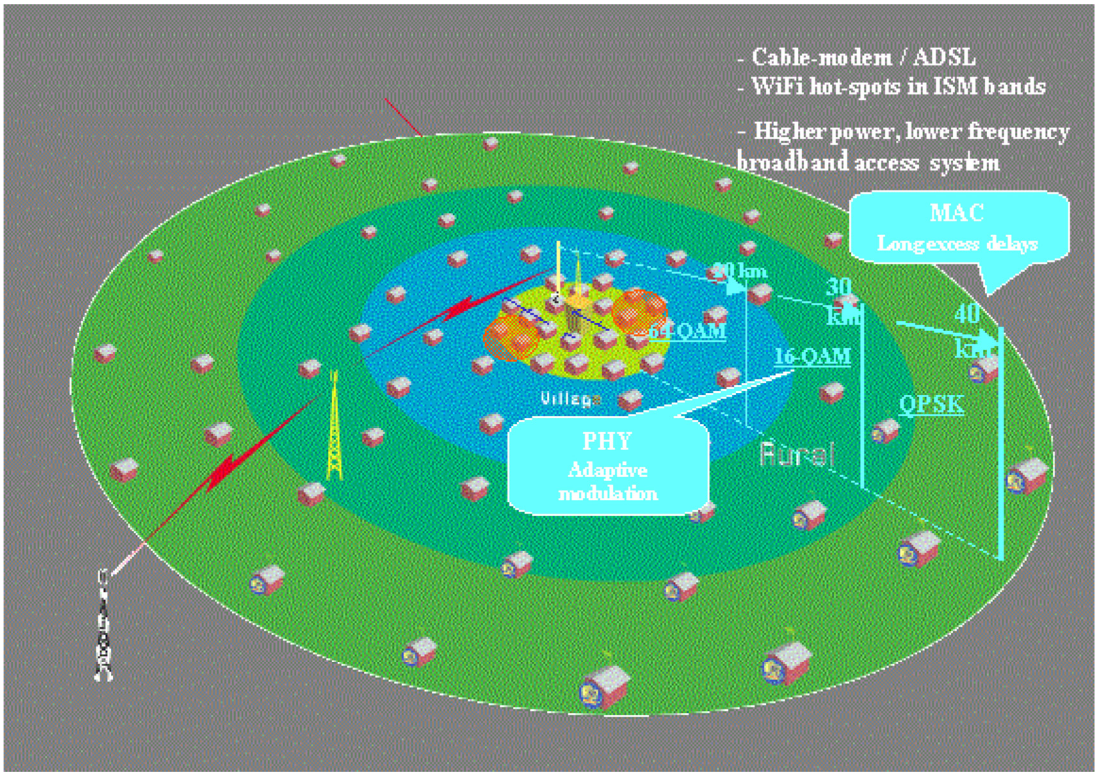

Fig.3 802.22 QAM Modes and distance [Pentz]

Channel bonding uses the primary channel and adjacent channel together to achieve a higher speed. In 802.11n, the protocol is able to bond 2 20MHz channels into one 40MHz channel, thus can transfer more data. 802.11af can bond with contiguous and non contiguous channel, thus can use the channel resource more efficiently and enhance the transmission speed. [Lekomtcev12] The protocols can double or quadruple their speeds.

With the application of OFDM, QAM Channel Bonding technology in wireless networking protocol, we can attain much higher speed than before and can transmit the data in shorter time.

3.7 Energy Harvesting

For distribution wireless devices in rural areas where there might not have power lines to supply energy, we might need the devices to capture energy themselves. The radio frequency, solar energy, wind energy, and thermal energy are all possible sources of energy. These energies are generally green energy and are good for environment.

In wireless sensor networks, it is very important to keep the on-board battery's life because it is very hard to supply those sensors with direct power source. Energy harvesting is very important for implementing a wireless sensor networks because it can get energy from renewable energy thus extend the life of non-renewable battery. Radio Frequency (RF) energy is becoming attractive because it can convert and store easily, and it also can easily send from the central station. Generally, there are three components in RF energy harvesting, transducer, condition and store. There are many protocols that deal with how to harvest energy efficiently. In [Eu12] proposed Adaptive Opportunistic Routing Protocol which can attain a higher throughput of energy harvesting.

As what is discussed above same protocols might use several measures to achieve the best energy efficiency. For example: 802.22 implements almost all measures mentioned above according to its environment. These technologies work together to save more energy.

4.0 Summary

From what is discussed above, Energy efficiency is in fast development in wireless network protocols because different stakeholders in wireless networking worry about design problem, green technology, cost and final user sanctification. There are several measures to achieve high signal-noise ratio with the same transmission power. These measures include reducing power use during both active and sleep modes, reducing inference among the same protocol device or with other protocols' device, selecting the frequency according to transmission distance, and having different transfer modes according to the size of payload.

Different wireless protocols adopt these measures according to the application of the payload and the environment conditions of applications. New technology in hardware will soon be integrated into software protocol to take advantage its energy efficiency property.

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6.0 Acronyms

AP	Access Point
APSD	Automatic Power Save Delivery
ASK	Amplitude-Shift Key
ECMA	European Computer Manufacturers Association
EIRP	Equivalent Isotropically Radiated Power
FCC	Federal Communications Commission
Hz	Hertz
LAN	Local Area Network
MQAM	m-ary Quadrature Amplitude Modulation
NRM	Network Reconfiguration manager
OFDM	Orthogonal Frequency Division Multiplexing
PSK	Phase-Shift Key
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Key
RF	Radio Frequency
S-APSU	Scheduled Automatic Power Save Delivery
SLS	Sector Level Sweep
SNR	Signal-Noise-Ratio
TV	Television

TVWS	Television White Space
U-APSU	Unscheduled Automatic Power Save Delivery
WirelessHD	Wireless High Definition
WLAN	Wireless Local Area Network
WSO	White Space Object

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