# Study of a Wake Up Radio Architecture for Home Multimedia Networks

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**Abstract.** A theoretical study on the impact of using a wake-up radio architecture in terms of energy consumption is proposed. The main objective is to reduce the overall energy consumption of a home multimedia networks. The energy consumed by the proposed wake-up radio architecture is compared to a classical WiFi architecture, for an ad-hoc scenario. The sleep time has an important role to compare the dissipated energy. This study demonstrates that the longer the sleep time the better the energy saved is obtained by the wake-up architecture.

## 1 Introduction

Nowadays wireless local area networks (WLANs) are widely deployed to provide internet access. Even at home, the number of devices to be connected to the internet increases and consequently the energy consumption of the home multimedia network grows. The necessity to reduce the energy consumption of the connected devices is an ongoing challenge for researchers in order to develop a green home wireless network. Worldwide consortiums gathering academic and industrial partners are formed and gave themselves as challenges to increase the energy efficiency by a factor of 1000 in the next few years [1].

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An approach to reduce the energy consumption of the home multimedia network is to shut down the radio-frequency (RF) part of the data interfaces when there is no communication demand, for example the "power save mode" used in IEEE 802.11 standard [2].

The energy consumption of the radio interface in the idle mode remains relatively high because of the low energy efficiency of the RF front-ends. For example, in the case of Linksys WRG54G Wi-Fi access point (AP), the maximum reduction in the energy consumption that can be achieved is 28.57 % [3]. This value represents the energy consumption of Wi-Fi interface compared to the entire energy consumption of the access point.

The wake-up concept has been introduced in the context of wireless sensor networks (WSN) as a way to optimize the battery lifetime [4] [5] [6] [7]. In WSN, the duty-cycle MAC protocols to reduce the overall power consumption exist. Wireless sensors in a duty cycle mechanism, should periodically sleep and wake their radio modules (like S-MAC, T-MAC, and B-MAC [8] [9] [10] [11]). High duty cycle reduces the latency but increases the energy consumption, while low duty cycle reduces the energy consumption but increases the latency. An appropriate trade-off between energy consumption and latency has to be achieved.

Another wake-up mechanism radio is to use a secondary low power transceiver to monitor the channel instead of the main data transceiver. In this paper, the wake-up architecture designs both the secondary low power transceiver and the main one.

Usually, the On Off Keying (OOK) modulation and the non-coherent envelope detection technique are used to design the low power secondary transceivers. This is because of their simplicity to implement, and their low energy consumption.

The use of a wake-up radio in the home wireless network, like personnel digital assistant (PDAs), has been firstly presented in [12]. In perspectives of this work [3], a low power sleep mode and an out of band wake-up mechanism has been adopted. A low power radio module to carry out of band control information is used to switch the WiFi access point (AP) into the sleep mode when no users exist.

The use of secondary low power wireless module, which has the same frequency and shares the same antenna with the co-located WiFi radio interface, was proposed in [13]. Based on modulation of the IEEE 802.11g frame length, the wake-up signal recognition needs an analogue to digital converter and a signal detection module that introduces more power consumption to the wake-up receiver.

The authors previous works [14] [15], present a wake-up radio architecture based on a frequency pattern identification of the address equipments. The secondary low power wireless module does not need baseband treatment of the identifier, and the decision to wake up is taken directly in the analog part. This implies a reduction of the energy consumption in sleep mode and a reduction of latency. In this paper an evaluation of benefits of using such architecture in terms of energy consumption is given.

The rest of this paper is organized as follows. Section 2 presents the proposed wake-up architecture and the identification technique. Section 3 presents the energy consumption estimation in an ad-hoc scenario. Finally, section 4 presents some conclusions and perspectives of this work.

## 2 Wake-Up Radio Architecture Description

The proposed wake-up architecture in [14] [15] has an ultra-low power secondary wake-up radio circuit that monitors the channel for the wake-up signal identifier. In order to minimize the energy consumption, the wake-up receiver is designed to be simple as possible, as seen in figure 1.

The wake-up circuit has two paths in which the input signal passes through, (i) the direct path which contains the multi-band filter that has the same bandwidth as the spectrum formed by the identifier signal (as the one presented in figure 2) and (ii) the complementary path contains the complementary multi-band filter, which has its pass bandwidth situated in the band stop of the direct filter. This configuration allows the wake-up radio circuit to eliminate the interference signal generated by other equipment present in the same area.

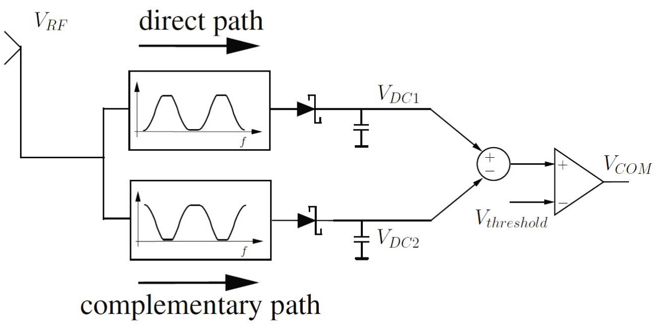


**Fig. 1** Wake-up radio circuit

The identifier is formed with an arrangement of a WLAN power spectrum, obtained by a selection of specific OFDM sub-carriers of the same group $G_i$ in the channel. figure2 shows an example of an identifier power spectrum. The 64 sub-carriers in the total band of 20 MHz are divided into 4 groups. Each group contains 14 neighbor sub-carrier of 312.5 KHz as shown below:

$$\begin{cases} G_1 = \{-28...-15\} \\ G_2 = \{-14...-1\} \\ G_3 = \{1...14\} \\ G_4 = \{15...28\} \end{cases} \tag{1}$$

Because of the complementary configuration of the architecture, the same DC voltage is obtained in the two paths when another signal is received for example the WLAN RF signal, in this case the difference of the two DC voltages is null.

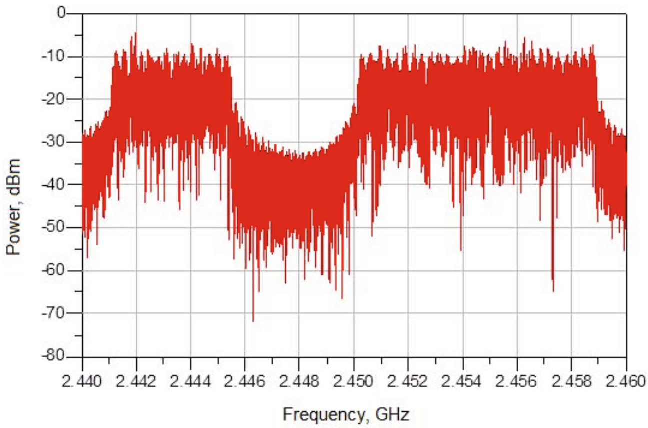


**Fig. 2** Power spectrum of an identifier $G_1$ =ON $G_3$ =ON and $G_4$ =ON

When the identifier is received, the output DC voltage VDC1 obtained from the rectifier has the maximum value and the DC voltage VDC2 is null. In this case, the difference between the two DC voltages is higher than $V_{threshold}$, and the activation signal $V_{COM}$ is generated as shown in figure 3.

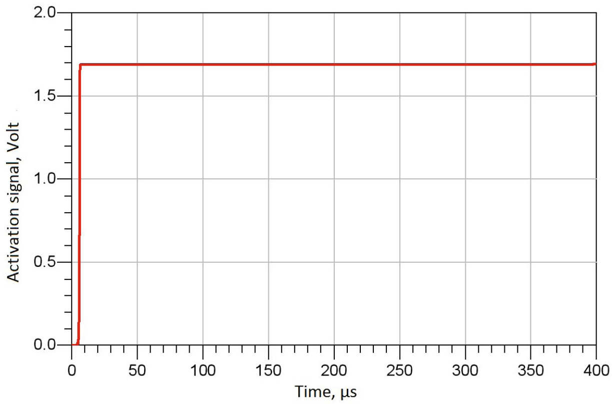


**Fig. 3** Wake-up signal activation $V_{COM}$

## 3 Energy Consumption Estimation

In order to calculate the energy consumption in a wake-up radio architecture, we need to consider the energy consumption of the wake up circuit and the main data radio interface in different communication states. In this study an ad-hoc scenario as shown in figure 4 is considered. Equipment 2 has its main interface “Main data 2” off, and its secondary wake-up radio receiver monitors the channel. When the wake-up signal identifier is sent by the equipment 1, then the equipment 2 passes from offline state to the receiving state, and the data transfer between the two main interfaces may begin.

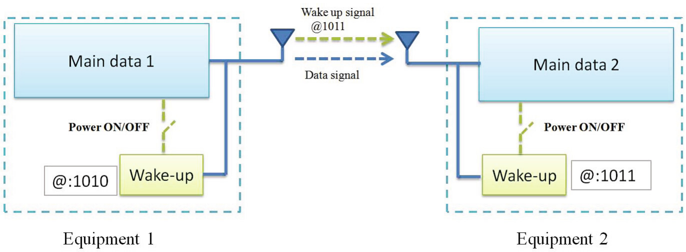


**Fig. 4** Proposed Wake-up radio architecture in an ad-hoc scenario

The main data interface used in the study is the 2.4-2.5 GHz transceiver MAX2830 [16]. Figure 5 gathers the different timing state and power consumption of this front-end. This timing state starts when the wake-up radio circuit receives during 400 $\mu s$ the identifier signal.

In the case of a classical WiFi the MAC layer controls the state of the physical layer (PHY). This is achieves by following the distributed coordinated function (DCF) access method [2]. All stations (STA) that intend to transmit frames must monitor the channel to determine if other STA are transmitting.

If the channel is idle for an interval of time that exceeds the distributed interframe space (DIFS), then the packet is transmitted. Otherwise, the STA monitor the channel until it is sensed idle for a DIFS interval. After that it generates a random backoff interval chosen in the range of [0,CW], where CW is the minimum contention window $(CW_{min})$. Next the STA will reduce this number by one each time an idle slot is elapses, or it is frozen when the medium is sensed busy.

The energy consumption $E_{WLAN}^{active}$ to transmit and receive one frame by the classical WiFi architecture is given by Equation (2). Also the energy consumed in the case of a wake up radio architecture $E_{Wake-up}^{active}$ is given by Equation (3).

Table 1 defines the relevant parameters used in the energy model. These parameters are taken from the MAC layer of a standard 802.11g, based on OFDM PHY, and the power consumption in different states (transmitting, receiving, idle and sleep) of the MAX2830 transceiver.

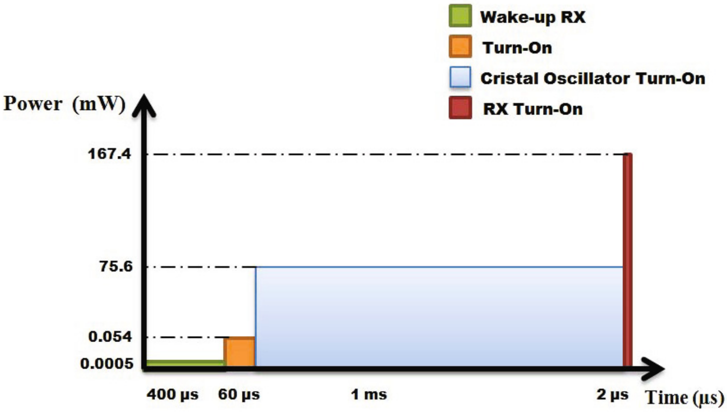


**Fig. 5** Time and energy spend to wake up with MAX2830

Equation (4) defines the energy consumed by the classical WiFi for sending and receiving one data frame for a classical WiFi architecture :

$$E_{WLAN}^{active} = (P_{TX} + P_{RX}) \times (T_{data} + T_{ACK}) + P_{idle}\left(2 \times T_{SIFS} + T_{DIFS} + T_{Backoff}\right) \quad (2)$$

Equation (5) defines the energy consumed in the wake-up architecture for sending and receiving one data frame :

$$E_{Wake-up}^{active} = (E_{WLAN}^{active} - P_{idle}\left(T_{DIFS} + T_{Backoff}\right)) + \left(P_{TX} + P_{wake-up}\right) T_{wake-up} + P_{Turn-On} \times T_{Turn-0n} + P_{oscil} \times T_{oscil} + P_{RX} \times T_{RX-On} \quad (3)$$

The energy consumed in sleep mode by the classical WiFi architecture is given by :

$$E_{WLAN}^{sleep} = 2 \times P_{sleep} \times T_{sleep} \quad (4)$$

The energy consumed in sleep mode by the wake-up architecture is given :

$$E_{Wake-up}^{sleep} = 2 \times P_{wake-up} \times T_{sleep} \quad (5)$$

The total energy consumed by the classical WiFi is given by :

$$E_{WLAN}^{total} = E_{WLAN}^{active} + E_{WLAN}^{sleep} \quad (6)$$

The total energy consumed by the wake-up architecture is given by :

$$E_{Wake-up}^{total} = E_{Wake-up}^{active} + E_{Wake-up}^{sleep} \quad (7)$$

**Table 1** Parameters for modeling the energy consumption using a MAX2830 802.11g transceiver

| Variable | description | value |
|---|---|---|
| $P_{TX}$ | Power consumed in transmitting mode | 800 $mW$ |
| $P_{RX}$ | Power consumed in reception mode | 167.4 $mW$ |
| $P_{idle}$ | Power consumption in standby mode | 75.6 $mW$ |
| $P_{sleep}$ | Power consumed in sleep mode | 75.6 $mW$ |
| $P_{wake-up}$ | Power consumed by the wake up secondary circuit | 500 $nW$ |
| $P_{Turn-On}$ | Power consumed by the radio interface in shutdown mode | 54 $\mu W$ |
| $P_{oscil}$ | Power consumed by the frequency synthesizer block | 75.6 $mW$ |
| $T_{data}$ | Time spend for sending 1500 byte of data at 9 Mbps | 2.42 $ms$ |
| $T_{SIFS}$ | Time of short interframe space | 10 $\mu s$ |
| $T_{DIFS}$ | Time of distributed interframe space | 28 $\mu s$ |
| $T_{Backoff}$ | Time of backoff | 67.5 $\mu s$ |
| $T_{wake-up}$ | Time of wake up identifier | 400 $\mu s$ |
| $T_{Turn-0n}$ | Time to pass from off mode to shutdown mode | 60 $\mu s$ |
| $T_{RX-On}$ | Time to pass from standby mode to receive mode | 2 $\mu s$ |
| $T_{sleep}$ | Time spend in sleep state | Variable |

Figure 6 shows the energy consumption of the classical WiFi, Equation (6), as well as the energy consumption of the wake-up architecture, Equation (7), when sending and receiving one frame of 1500 bytes with a rate of 9 Mb/s.

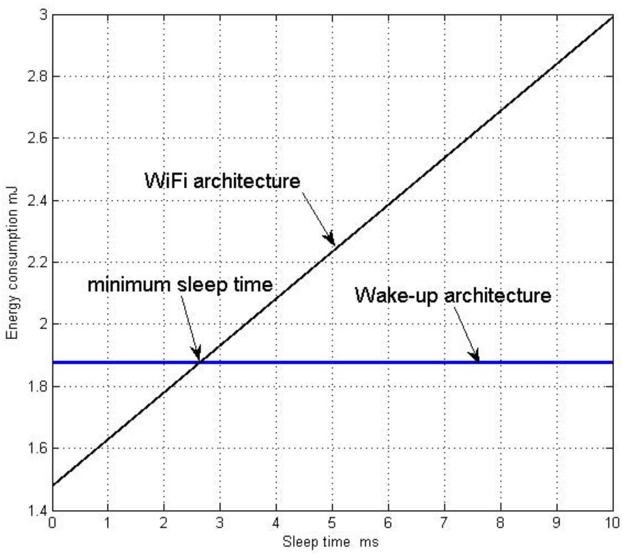


**Fig. 6** Energy consumption vs sleep time

In Equation (8), $T_{sleep}^{min}$ represents the sleep time where the wake-up architecture has the same energy consumption as a classical WiFi architecture. From Equations (6) and (7) we get the minimum sleep time $T_{sleep}^{min}$:

$$T_{sleep}^{min} = \frac{1}{2} \times \frac{E_{Wake-up}^{total} - E_{WLAN}^{total}}{P_{sleep} - P_{wake-up}} \quad (8)$$

If the sleep time is less than $T_{sleep}^{min} = 2.6\ ms$, the energy consumption of the wake-up architecture is higher than the energy consumption of the classical WiFi architecture. This is due to the energy consumed by the main data when switching from offline to the receiving mode.

When the sleep time is higher than $T_{sleep}^{min}$, the energy consumption of wake-up architecture is less than a classical WiFi architecture, because of it low energy consumption in sleep mode $(500\ nW)$.

In figure 7 the energy consumption in function of the sleep time at different data rate is plotted. The figure shows that when the enhancement condition is respected $\left(T_{sleep}^{min} > T_{sleep}\right)$, the higher is the sleep time, the better is the enhancement.

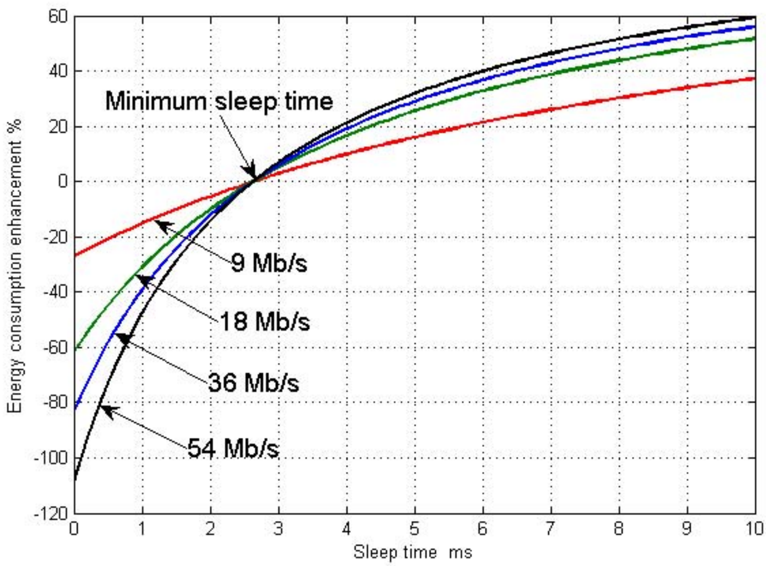


**Fig. 7** Energy consumption enhancement vs sleep time

Indeed when the sleep time is equal to 10 $ms$, the wake-up architecture achieves up to 40 % ( $resp$ 60 % ) of energy saving compared to a classical WiFi architecture at 9 Mb/s ( $resp$ 54 $Mb/s$ ) data rate. Moreover, we notice that the higher is the data rate better is the energy saving, this mainly due to the transmission time of the packet which is inversely proportional to the data rate.

## 4 Conclusion

In this paper, the energy consumption of a proposed wake-up radio architecture has been evaluated and compared to a classical WiFi. This study demonstrates that, with respect to minimum sleep time $T_{sleep}^{min}$, the wake-up architecture saves more energy than the classical WiFi. Future works include analyzing a network scenario, with a traffic rate (on the order of hours) to find the maximum sleep time in different traffic loads. However in such scenario, latency and false wake up should be studied in order to quantify the robustness of the proposed architecture. Moreover, a prototype will be manufactured in order to have concludent measurements of energy consumption and time latency.

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