LOW POWER WI-FI™ (IEEE 802.11) FOR IP SMART OBJECTS

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Abstract: IEEE 802.11 (Wi-Fi) is normally used to provide high-speed, moderate-range IP data transfer between computers or handheld devices and local-area-networks, where datarate is the main design parameter. Systems optimized for this application are fast but not energy-efficient. However, with appropriate system design and usage models, Wi-Fi devices can operate in a power-efficient fashion, and achieve multi-year battery life in sensors and other low-power applications. Low-power Wi-Fi devices have the advantages of native IP-network compatibility and well-known protocols and management tools.

Introduction

Until recently, Wi-Fi was not considered viable for battery powered sensor network applications. Wi-Fi silicon had been targeted at laptops and cell phones, where the battery can be recharged after several hours of operation, or at line-powered devices such as access points. With the growing market for smart objects and wireless sensors, companies such as GainSpan have developed application-specific integrated circuits that are optimized for sensing applications. These products achieve a similar power profile to other low power wireless PHY/ MAC architectures, while leveraging the benefits of a well-established protocol:

- A huge installed base of over 2 billion Wi-Fi-certified devices;
- A vibrant standard and industry alliance of close to 300 members;
- Well-proven encryption, authentication and end-to-end network security;
- Mature network management systems.

These benefits make low-power Wi-Fi ideal for residential and commercial building applications.

A Power-Efficient Protocol

The perception of Wi-Fi as a power hungry protocol arises from the manner in which Wi-Fi systems are designed and used in conventional applications today, and not from any intrinsic inefficiency in the IEEE 802.11 protocol [1]. With energy consumption of 1-17 Joules per Mbyte transmitted for conventional high power Wi-Fi, depending on the protocols or the devices used [2], even the least efficient device running on a AA battery could transmit 1 Mbyte per day for 4 ***years***. The most efficient device is potentially capable of operating for decades on a battery, although today's battery technology is limited to 10-20 year lifetimes even with no intentional current drain.

How is Low Power Wi-Fi Different?

While conventional high power Wi-Fi chips are optimized for fast response, low latency, and high data rates, low power Wi-Fi chips are optimized for low power consumption, particularly when the device is in Standby mode. For example, in conventional applications the device may actively listen to the channel even when no data is being transmitted, to provide good response and low latency. Low power Wi-Fi minimizes power consumption when data is not being transferred. A representative operating scheme for a typical low-power application is summarized in Figure 1. After an initial set of tasks associated with startup, a low-power device spends the great majority of its time doing nothing. The device must wake up periodically to support various application-related or network-related tasks. In the example shown in the figure below, the device sends a packet once per minute to reassure the Access Point that it is still present and active, preventing disassociation. The type and frequency of this packet depend on the AP in use. Every 2.5 minutes, the low-power device awakens to send sensor data. Twice a day, the device sends a Configuration Trap to a Simple Network Management Protocol (SNMP) server, to check for pending configuration changes (such as a new sensor time interval). Between each of these very brief operations, the device is in a low-power Standby state. Even during the periods in which it is awake, the device is actually sending or receiving data for only a small portion of the time.

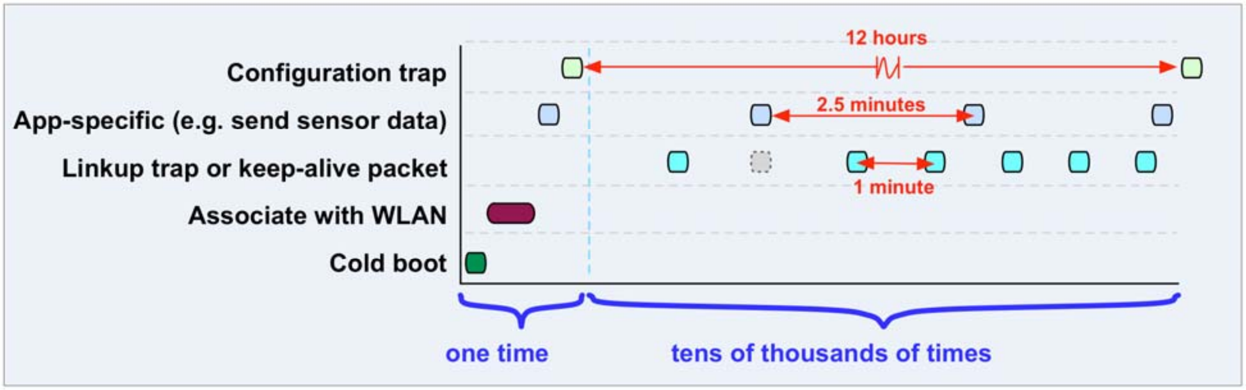

Figure 1: Typical low-power Wi-Fi operation scheme.

In order to minimize the power consumed during the vast majority of the time, in which no data is being transferred, the following changes to conventional design approach must be implemented:

- The device must be highly integrated to shorten connections, minimize capacitances and inductances and reduce overall energy consumption. All major system functions, including application programming, task management and network functions, radio management, encryption, MAC and baseband processing, and the radio transceiver itself, should ideally be incorporated on a single die.
- The device must be capable of flexible and rapid power management, including both fast-response states with reduced power consumption, and very-low-power Standby or Idle states employed when no activity is required from the device.
- It must be possible to awaken the device from its low-power states to a fully-operational condition in a short time, either on a pre-arranged schedule or by an external input.
- Network operations must be arranged so that connection maintenance and remote device management are accomplished with minimal drain on the energy resources of the device.

Figure 2 shows the example of GainSpan's System-On-Chip design satisfying these constraints:

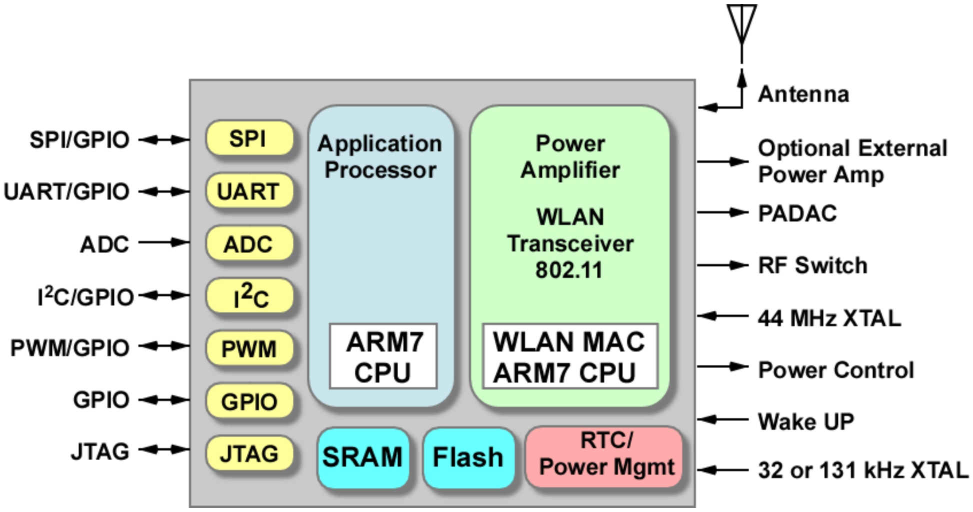

Figure 2: Block diagram of a highly-integrated low-power Wi-Fi device (GainSpan GS1010).

An integrated architecture allows very effective power management. Processor and component clocks can be gated off very rapidly to reduce power consumption when a specific function is known to be idle, with full function restored in one clock cycle when processing is ready to continue. In this particular chip, either or both CPU's, as well as a number of other functional blocks, can be independently gated to flexibly adjust the configuration of the chip to current processing needs, minimizing energy consumption. The whole chip can be rapidly put to sleep, with the high-speed 44 MHz clock oscillator shut down, to reduce power consumption without loss of data; the system can recover from this Deep Sleep state back to full operation in a few milliseconds. These flexible low-power states allow system designers to take full advantage of such features as 802.11 power save operation, since the system can accurately awaken at expected beacon times, rapidly respond to beacon data and request delivery of buffered packets, and return to low power consumption as soon as the requisite functions are complete. In this fashion, low-power nodes can communicate with each other and with networked devices, with the power-hungry always-on packet buffer function taken care of by the powered Access Point. A device can also be awakened asynchronously using one or more input pins, to deal with alarms or unpredictable events that require prompt response.

Finally, an ultralow-power Standby state is also available to minimize energy consumption during long periods when it is known that the system will be idle. In this mode only the RTC block is active and power consumption is a few microwatts. The RTC block timer permits the system to awaken at programmable intervals. Alarm inputs are also provided to permit unscheduled wakeup. Volatile data is lost in Standby, so some overhead is encountered in storing state and configuration information, and restoring the same when the system awakens, but the transitions are still much faster and less energy-intensive than the comparable functions when managed by a host CPU through a conventional serial, USB, or Cardbus interface.

A highly-integrated architecture thus permits a low-power Wi-Fi system to provide high performance and low latency when data is actually being transmitted and received, while very efficiently minimizing the time spent consuming power when no data is being transferred. Rapid and efficient power management allows small packet transfers to be completed with only a modest increase in per-bit overhead compared to conventional systems.

The use of such an integrated system can provide substantial performance improvements in those parameters important for low-power operation, without compromising Wi-Fi compatibility. As shown in Table 1, low-power Wi-Fi systems have much lower power idle states available, and can transition between active and idle states much more rapidly, than conventional Wi-Fi systems. They also achieve less remarkable but still substantial improvements in power consumption during data transfer operations, in part related to the lower transmit power used for lower datarate sensor applications. As sensors spend most of their time in Standby mode, the average power consumed is generally dominated by power consumption in this mode. Power consumption in transmit and receive modes have little effect on the overall power consumption when transmit events are infrequent.

Table 1: Comparison of conventional and low-power Wi-Fi typical performance.

Parameter		Conventional Wi-Fi	Low-Power Wi-Fi	units
Power consumption	Standby / Idle	NA*	<4	µW
	Processor + clock sleep	13	0.2	mW
	Data processing	115	56	mW
Receive sensitivity, 1 Mbps		-91	-91	dBm
Time to wake from Standby		NA*	10	ms
Time to wake from processor+clock sleep		75	5	ms

*Not applicable: comparable state does not exist.

Low Power Wi-Fi = Standard Wi-Fi, IP

Although, as described earlier, low power Wi-Fi chips are optimized for low power consumption typical of sensor applications, low power Wi-Fi conforms to the IEEE 802.11 standards and benefits from the standards' evolution in areas such as security (802.11i), meshing (802.11s) and Quality of Service (QOS, 802.11e). Relative to other technologies for low-power applications such as Zigbee/802.15.4, low power Wi-Fi takes advantage of the benefits conferred by the well established IP and Wi-Fi protocols:

- Since Wi-Fi sensors use IP-over-Ethernet networking environment, there is no requirement for an expensive internetworking gateway to handle functions like network address translation or custom provisioning. Sensors are able to get unique IP addresses either via static assignment or through DHCP queries, and are able to support ARP for address conflict resolution.
- Sensor nodes can be managed and configured remotely using SNMP, a well-supported network management protocol. The node can have an SNMP agent that can respond to the SNMP manager's GET and SET commands, and send SNMP configuration traps to the manager.
- Support of well proven Wi-Fi link-layer encryption and authentication and related Wi-Fi Protected Access (WPA/ WPA2). For example, Pre-Shared Key (PSK), Extensible Authentication Protocol (EAP), as well as Transport layer security (TLS/ SSL) are all supported by GainSpan's SOC product.
- As opposed to other systems operating in the 2.4 GHz unlicensed band, and in applications where other Wi-Fi stations constitute an important source of traffic, Wi-Fi sensors can benefit from 802.11's provision for collision avoidance. Every Wi-Fi packet contains a Network Allocation Vector (NAV), informing all stations that hear it that the sending Station wishes to reserve the medium for a time interval long enough to complete the current transmission. A low-power Wi-Fi device can use the NAV value received to reduce power consumption during the requested interval, and avoid attempting a transmission which is likely to collide with that of another Station. Devices that cannot interpret Wi-Fi packets may attempt a transmission during the period reserved by the NAV, and suffer a collision. The transmitted packet is likely to fail to reach its destination, and is either lost, or requires retransmission, in either case wasting valuable node energy.

- Wi-Fi systems benefit from a large installed base and consequent broad-based familiarity with configuration, use, and troubleshooting at the physical and link layers.

Low Power Wi-Fi Applications and Availability

Low power Wi-Fi is suitable for almost any application where remote sensing or controlling is needed or desired, such as HVAC and appliances monitoring and controlling in homes or businesses, building automation, asset or people tracking or temperature monitoring for temperature-sensitive goods.

Low power Wi-Fi semiconductor solutions are available from several chipmakers including GainSpan, several component manufacturers have built modules based on the available chips, and products are now starting to appear on the market addressing applications such as thermostats, water heaters, HVAC systems, blood pressure, glucose monitoring and other healthcare devices, asset or people tracking tags, etc.

References

1. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications ", IEEE 802.11-2007, June 12, 2007.
2. "Power Consumption and Energy Efficiency Comparisons of WLAN Products", Atheros Communications, 2003.

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