Abstract:
This white paper explores TI’s proposed wireless connectivity solution for enabling feature-rich wireless connectivity for E-book readers. Based on its established connectivity solutions, we believe TI’s solution is uniquely positioned to provide a comprehensive wireless connectivity solution which is perfectly fit for E-books, leveraging the gained knowhow from integration into mobile handsets. The paper will explore the WLAN & Bluetooth combo solution, providing a high-level overview of the HW and SW architecture. Special focus will be put on the E-book typical use case and the related WLAN activity.

Keywords: Wireless connectivity, WLAN, E-book use cases
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Introduction

In recent years, increasing demand for wireless connectivity is being witnessed in a vast majority of consumer electronic devices. Striving for increased mobility has further enhanced this demand, targeting to achieve an always connected user experience.

Among all technologies WLAN is one of the most common and desirable wireless communication due to several reason which make it a compelling alternative. WLAN is gaining increasing plausibility due to its ease of deployment, operation in a free spectrum bands, relatively easy configuration, and the entailed cost model which fits both enterprise and home end users. The large install base acts as a catalyst for further increase in WLAN proliferation.

From technical perspective, it seems that WLAN provides a reasonable capability bundle allowing high throughputs, for a reasonable range at a reasonable cost. From SW integration perspective, the fact that the WLAN protocols directly binds into the IP layer model allows for seamless integration of IP-based applications. Nevertheless, some aspects of the WLAN protocol pose challenge when integrated into a mobile device. Among those, it is worth to mention the power consumption challenge, coexistence with other co-located technologies either operating in the same frequency bands (e.g. Bluetooth) or adjacent (e.g. cellular), driver code footprint and some other.

This whitepaper explores the wireless connectivity subsystem of an E-book reference design and its capabilities. It is based on TI’s single-chip combo device, supporting both WLAN & Bluetooth. The proposed solution enables a feature-rich wireless connectivity extension to the E-book reference design. TI’s wireless connectivity solution complete offering encompasses HW reference design, comprehensive SW package and proven system understanding based on gained knowledge and vast experience in the mobile handset.
Wireless Connectivity Subsystem

Overview

The proposed wireless connectivity solution is based on TI’s 6th generation WLAN device, brand named WiLink™ 6, which is actually a combo device including Bluetooth entity alongside the WLAN entity. WiLink™ 6 is a chipset hearted with the WL127x core device and accompanied by an external off-the-shelf SMPS device and a front-end module.

The 127x is a mixed-signal, 65nm, combo device encompassing WLAN and Bluetooth entities (FM RX & TX radio is also included but is left beyond the scope of this white paper). Both comprise of MAC, BB and radio capabilities for each of the technologies.

The 1271 flavor is limited to 2.4GHz band (supporting 802.11bgn), while 1273 is supporting both 2.4GHz and 5GHz bands (supporting 802.11abgn). Both devices are pin to pin compatible. Beyond that, the WLAN function is adherent to a wide range of WiFi-alliance certification programs, supporting both home and enterprise feature set. The Bluetooth function is Bluetooth 2.1 + EDR compliant with integrated BLE support. Thus, the solution is highly versatile and interoperable.

HW Architecture

The WiLink™ 6 chipset is composed of a core device (127x) and accompanied by an external off-the-shelf SMPS device and a front-end module. The front-end module contains a PA, a balun and a 3-way RF switch.

Being a triple-radio design WiLink™ 6.0 employs special techniques to address radio coexistence challenges. Special care is taken in integration of WLAN and Bluetooth since both operate on the same frequency band. TI’s proprietary unique set of algorithms addresses this issue such that it allows the use of a single antenna shared among WLAN and Bluetooth for the 2.4GHz band.

Overall solution size is sometimes a key factor in mobile devices. Due to the small footprint that the 127x core device has, the resulting total solution size is less than 80 mm².

Power scheme

The device has two 1.8V voltage rails, one for the IO ring (VIO) and the other for the device core (V1.8). In typical battery operated configuration, an SMPS is used to translate VBAT to 1.8V with adequate performance characteristics to guarantee system performance. It is possible to connect the device directly to any other pre-regulated 1.8V in the system as long as all electrical specifications are met.

Clock scheme

The device is operated with two external clock sources. A high frequency, high performance source (one of the following: 19.2, 26, 38.4, 52 MHz) and a low frequency square-wave 32.768KHz used for low power sleep mode operation. Both TCXO and XTAL options are supported for the fast clock.
Reset scheme
Separate reset signals are available for each of the functions (Bluetooth and WLAN). A reset signal assertion will reset the respective core, transparently to the other core.

Host I/F
WLAN support an either SDIO or SPI I/F. The SDIO I/F can run up to 26 MHz delivering 100 Mbps raw data rate while SPI support 52 MHz thus providing up to 52 Mbps.

SW Architecture
The WiLink™ 6 solution will be supplied with a comprehensive SW package allowing development and integration of the device core functions. The complete package is named MCP (Mobile Connectivity Package) and contains all related SW content that is required to run the product.

Special care has been taken to address the following fundamental guidelines:

- **Ease of porting**
  - Clear separation of OS abstraction layer
  - Clear separation of platform dependant content

- **Ease of integration**
  - Supporting standard OS command interface (e.g. WEXT)
  - Optimized performance with OMAP application processors family

- **Data-path enhancements**
  - Allowing higher throughputs and lower CPU load (4 MIPS/MHz)
  - Smaller number of transactions per packet
- Interrupt pacing
- Packet aggregation

**Host offload**
- FW based periodic scan capability
- FW based rate management

Figure 2: SW Architecture Block Diagram
The WLAN driver provided with the package follows the aforementioned guidelines and provides a wide range of capabilities including multiple roles support (STA, AP, P2P) and related connection management activities; security (supplicant I/F); QoS; scan and roaming support with external hooks for end-user applications and many more.

Figure 3: WLAN Driver Partition
Use Case Analysis

Description

In this section we will attempt articulating a typical E-book user profile with respect to the WLAN activity. We shall then attempt to further analyze it and identify the key performance criteria and expected behavior.

Typically, an E-book user will be using its connectivity link for two purposes. The most fundamental use case is utilizing the wireless link for e-book content download. A secondary use case might be to share content with peer e-book users or downloading content to/from a nearby storage device. Newer device may desire to expand the support to more advanced use cases such as oriented data feeds (e.g. library content updates, adware content push etc.) or generic internet browsing. The e-book readers may further evolve to provide enriched experience by allowing to some level of multimedia content (either audio or combined audio/video). In the latter case Bluetooth capability might be desirable in order to maintain the complete wireless experience. For the scope of this white paper we shall limit ourselves to the fundamental use case.

Unlike a computer or MID (Mobile Internet Device), the end-user is not expected to have direct interaction with the underlying WLAN subsystem. The interaction is limited to one-time configuration of expected behavioral guidelines and it is expected that the rest will be handled automatically.

The considered use case may be composed of the following phase:

1. **Not connected:** automatically search for WLAN to connect
2. **Establish connection:** connect to the network
3. **Connected:** maintain connection ; notify application to search for relevant content
4. **E-Book download:** data transfer of actual content

Figures of merit

In the discussed use case, the fundamental figures of merit that may have direct impact on user experience are different for each of the profile phase and captured in the table below.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not connected</td>
<td>Average idle current</td>
<td>During this phase the WLAN is systematically looking for APs to connect to using scan operation; the system may potentially remain in this phase for long periods of time.</td>
</tr>
<tr>
<td>Establish connection</td>
<td>Security capability set</td>
<td>This phase encapsulate the connection attempt ; wide variety in the security module will expand the connection possibilities hence overall service provisioning</td>
</tr>
<tr>
<td>Connected</td>
<td>Average idle current</td>
<td>During this phase the most critical parameter is the background current that is drawn while connected; since most of the time the device is connected but no actual data transfers take place; application layer may choose to trigger information retrieval.</td>
</tr>
<tr>
<td>E-book download</td>
<td>Throughput</td>
<td>Actual download. During this phase the key performance parameter is throughput in order to minimize activity duration and reduce power thereof.</td>
</tr>
</tbody>
</table>
Target Performance

Not connected

While not connected, scan activity is taking place in the background. There are two types of scans: passive and active. Both have a set of configuration parameters that govern the overall current draw. In this phase the device issues scan activity, collects results and returns to sleep. It is critical to understand the underlying trade-off between the average power consumption and average time-to-connect in this case.

Since the scan activity is repetitive (if not truly periodic) by nature, increasing the period time will result in substantial current reduction while increasing the average time to connect/re-connect.

- Passive scan

- **Description:**
  - Passive scan is conducted implicitly by the FW in a periodic manner
  - No active transmission involved, information is collected from beacons transmitted by the APs
  - Under regulatory domain restrictions, scan for first connection is done in such manner since transmission restrictions are unknown

- **Current Profile**
  - Scan is invoked in a periodic manner
  - RX windows are opened on each of the channels defined for scan
  - Device is listening on the selected channel for a predefined duration or until beacons are received (whichever comes first)
  - Newly discovered channels reported, device resumes sleep

- **Controlling Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>Period for activating the scan</td>
<td>60 s</td>
</tr>
<tr>
<td>Channels</td>
<td>List of channels to scan</td>
<td>1, 14</td>
</tr>
<tr>
<td>Max dwell time</td>
<td>Max time to listen on a channel</td>
<td>500 ms</td>
</tr>
<tr>
<td># of Beacons</td>
<td>How many Beacons to capture</td>
<td>1</td>
</tr>
</tbody>
</table>

- **Current consumption example:**
  - Using the numbers above
  - Worst case, no channel active: \( \sim 7.5 \text{ mA} \)
  - Typical case, 3 channels active: \( \sim 6.5 \text{ mA} \)
  - Substantial reduction is achieved by dynamic increase of the period in case of no activity and making it activity aware.
A smart algorithm may be sought to reduce the power consumption overhead by dynamically reducing the period after relatively long duration of no activity. However, this needs to be done carefully such that prolonged times to first connection will not be experienced. This issue can be overcome using stochastic distribution of the actual scan periods. Additionally, active scan may be used with a limited set of parameters (e.g. output power limitation) in order to obtain a list of APs in close proximity. It may further be used to acquire the country IE which carries regulatory related information and once obtained resume operation in active mode.

**Establish connection**

While establishing connection, the wider variety of supported authentication paradigms the better. This is primarily provided by the supplicant component which is external to the WLAN driver and manages authentication and key exchange mechanism.

Furthermore, it is beneficial to implicitly ensure end-to-end communication once connected in order to deliver best user experience and avoid frustration. In order to achieve this goal a small piece of code should generate a set of predefined transactions to a predefined destination, which in turn will reply with a predefined set of transactions. Once complete it is clear that end-to-end communication has been successfully established.

E-book vendor may desire to utilize the transaction exchange to obtain other relevant information located on the network such as book library updates etc.
**Connected**

Once connected, the device may trigger the application and notify its new state. This may serve for triggering pending data retrieval, meta-data information retrieval etc. In the vast majority of the connection time, the connection will remain idle. In which case, device will react only to beacons received at the STA.

The idle connect profile is determining the standby time of a device under WLAN coverage assuming no other activity is taking place. Therefore, beacon reception profile was shaped to minimize average current consumption. In WiLink™ 6 this current is circa 0.7 mA.

**E-book download**

While actually downloading the e-book content, the most critical parameter is the achievable throughput. This has direct effect on the overall activity duration, hence the current as well as the user tolerance to wait for download completion.

For this purpose, the 802.11n support perfectly matches mobile and nomadic applications, focusing on single stream 20MHz channels; and avoiding the system overheads imposed by 40MHz bandwidth and MIMO operation and the entailed costs. The 802.11n support on WiLink™ 6 provides approximately x2 TCP rates based upon:

- Increase in PHY rates allowing up to 65.5 Mbps (72 Mbps with SGI) and RX STBC
- Reduction of MAC protocol overheads utilizing packet aggregation (A-MPDU)
- Improved range vs. rate behavior allowing better rates for a certain range

This benefit may be witnessed in the following graph capturing the throughput vs. range of legacy and 802.11bgn solution performance.
The impact over power consumption and related device lifetime impact can be learned from the following example use case, in which a 50 MB file is downloaded over the network with good WLAN coverage. The device is assumed to have a 850 mAh battery.

<table>
<thead>
<tr>
<th></th>
<th>11bg</th>
<th>11bgn</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Download time [s]</strong>:</td>
<td>16.7</td>
<td>9.8</td>
</tr>
<tr>
<td><strong>Invested energy [J]</strong>:</td>
<td>8.6</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Available use time [hr]</strong>:</td>
<td>320</td>
<td>375</td>
</tr>
</tbody>
</table>

*use time is calculated assuming WLAN budget out of overall system consumption is ~25% in the 11bg case*
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