Wi-Fi® audio: Capabilities and challenges

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Abstract

The following white paper aims to present an overview of the challenges in providing a high-quality, uninterrupted audio experience using Wi-Fi® technology.

It will be shown how the connectivity component may not only impact and determine the end-user experience—but also may have an impact on the overall system design and cost.

Wireless audio introduction

The rise of digital music has made it possible to carry your music collection on a hand-held device, but it wasn't until the wireless "revolution" that people were able to overcome the need to constantly move audio equipment and its cables around the house.

Wireless speakers have been growing in popularity for some time, allowing users to stream audio from a range of devices to speakers around the home using a wireless connection.

At first, there were simple devices, such as short range FM transmitters/receivers, which were most commonly used for playing music either from portable audio devices in car stereos with no auxiliary input jack. However, the low-power range of most transmitters, to avoid interference due to regulatory issues, is relatively short and also depends on the quality and sensitivity of the receiver, environment obstructions and elevation.

In addition, the audio quality provided by FM transmitters is also limited compared to other technologies.

Recently, along with developments in *Bluetooth*® specification and the standardization of A2DP, there has been a significant rise in popularity of Bluetooth speakers.

Bluetooth audio had several advantages over short range FM, such as native support for higher quality audio. This technology is both common and cost efficient, and enables playback when a Wi-Fi network is not present.

In parallel, several proprietary solutions have emerged to address specific equipment requirements; however, these systems are closed and usually relatively expensive.

Wi-Fi audio

In the recent years, more and more audio equipment vendors have started to look into adopting Wi-Fi as the next technology to enable high-performance audio distribution around the home environment.

The features of Wi-Fi technology are compelling and can assist vendors in delivering new and exciting features.

The benefits of using Wi-Fi for audio distribution are:

- It is a standard technology, with widespread adoption
- It offers higher network capacity over other technologies, allowing high-quality audio to be delivered
- Wi-Fi has longer range coverage compared to other wireless audio technologies

- It has native support for IP protocol (required for online music services)
- Wi-Fi speakers support autonomous online playback (no additional mobile device is required to be present)
- Wi-Fi forms the backbone of music streaming technologies such as AirPlay® and Google Cast™

Challenges

Building a quality Wi-Fi audio product involves several challenges.

Link robustness

The robustness of the wireless link has the potential not only to impact the user experience, but also impacts the hardware and software design (and therefore cost) of the audio solution.

In the following section, several key factors, which are the foundation of a good quality link, are detailed.

Good RF performance

Several factors can impact RF performance:

- **Device sensitivity** – Range is an important requirement for most, if not all, wireless applications. Longer range, which is achieved with greater receiver sensitivity, is a desired feature among wireless product manufacturers. Extended range achieved in this fashion provides an excellent cost benefit to the customer. **Receiver sensitivity** is defined as the lowest power level at which the receiver can detect a wireless signal and demodulate it successfully. As the signal propagates away from the transmitter there is a decrease in its power density. This makes it more difficult for a receiver to detect the signal as the distance rises. Improving the sensitivity on the receiver allows the radio to detect weaker signals, and can dramatically increase the operational range. Sensitivity is the crucial factor in the decision-making process since even slight differences in sensitivity can account for large variations in functional range.
- **TX power** – RF transmit power is an important performance parameter for a wireless local area network (WLAN) system. It is important because it can impact system regulatory compliance, and most importantly, the effective range. The transmit power of two systems that are otherwise similar can also provide an indication of which system supports the greatest communication range to the receiver.
- **Antenna diversity** – Since a transmitted signal is subject to reflections and refraction on walls, surfaces, and so forth, the receiving node will see signals differing in phase and amplitude. Using more than one antenna allows for the evaluation of different multi-path scenarios to avoid or reduce the effects of fading and interferences. Diversity is used to describe a strategy for choosing the better of two paths of transmitting or receiving an RF signal in order to maximize the possibility that a packet will be correctly received.

Bandwidth

While most online audio streaming services (using stereo) do not require high bandwidth (up to 320 kbps), some high-quality services may stream at 1411 kbps. Even so, these figures are far below what most wireless devices can achieve today.

More high-end audio playback, such as Dolby® 5.1, 7.1 or a multi-room environment, presents greater demands from a bandwidth perspective.

When an audio system is deployed in a real-world environment, congested with multiple devices transmitting at once, collisions and retransmissions may occur which can have a negative impact on audio quality if they are not handled well.

In addition, if there are any speakers (or other equipment), which is at the edge of the access-point coverage area—the data rates of the link may be lower, thus degrading overall network performance.

Smart rate management algorithms may be required to handle such complex environments.

Network latency and jitter

Network **latency** is defined as the amount of time a frame takes to traverse from one designated point to another inside a given network.

Network **jitter** is defined as the variation in the delay of, or interval between, received frames.

The audio source transmits frames containing encoded audio samples in a continuous stream and spaces them evenly apart. On the receiver side, these frames are decoded into audio samples and placed in a playback buffer.

The playing device then periodically, at fixed intervals set by the audio decoder, pulls audio samples from the playback buffer, and outputs them as sound. As such, the playing device must have a ready sample to play at those fixed intervals, otherwise, it will either play a "silent" frame or the previous frame received. This will sound distorted or choppy to the listening audience.

Several factors, such as network congestion, improper queuing and misconfiguration may lead to a variable delay. This variation may cause problems for audio playback at the receiving end.

If the jitter is high, the playback may experience gaps while waiting for the arrival of new (delayed) frames.

Both latency and jitter eventually also affect the size of the audio playback buffer.

As the latency and jitter rise—the size of memory required for the audio playback buffer may increase. A larger audio playback buffer either means less memory for other applications/code, or larger memory, which results in a more expensive solution.

A bigger audio playback buffer also means that whenever the music is started, this buffer has to be filled with audio samples, which most of the time creates an additional delay before playback actually starts.

Low latency is also very important for video/audio synchronization (also known as "lip synch").

In this case, an audio stream is transmitted to match a video being played. There is an acceptable range of delay tolerable by the human mind. While different standardization bodies may recommend different ranges for different applications, it is commonly acceptable to limit the delay at 20–30 ms.

Dolby, for example, specifies 20-ms delay budget for overall system between audio-in at the transmitting device and audio-out at the playing device.

Packet loss

Regardless of which wireless technology is used, there is bound to be some level of packet loss while working in highly congested environments.

Packet loss may occur from collisions with other devices transmitting at the same time, interference from other devices operating on the same frequency or simply a weak signal.

The level of packet loss in a given environment may affect the audio distribution protocol and therefore the design and cost of the solution.

If a device does not perform well enough in a congested environment and packets simply get lost, the audio transmitter device may need to transmit more data to compensate for potential lost data and consume more bandwidth. For example, in the worst-case scenario, it may transmit each audio sample twice, just in case it may get lost.

Normally, packet loss is handled by simply retransmitting the lost frame; however, in time-critical use cases, such as audio, a given transmitted sample may not be relevant by the time it gets retransmitted simply because its due time to be decoded and played has passed.

Other than retransmitting the frame, more sophisticated audio distribution implementations are able to adjust the parameters of the link in real-time.

Interoperability

A very important factor in a robust Wi-Fi solution for wireless home audio is interoperability.

Interoperability is the wireless device capability to function and provide the best performance when used in conjunction with other wireless devices based on different chipsets and software.

As Wi-Fi devices have become very popular in the home environment—the present wireless home environment is built from a variety of access-points, laptops, PCs, mobile phones, tablets, game-consoles and more. Each of these products is equipped with a different wireless chipset and supporting software. These devices must interoperate together on a basic level.

While most devices will be **Wi-Fi CERTIFIED™**, which guarantees basic functionality, performance and interoperability amongst different products, there are some aspects of interoperability which may only present themselves in highly sensitive applications, such as wireless audio streaming.

RTS/CTS (Request to send / clear to send) usage is one example of such interoperability issues which may impact network performance and eventually user experience.

RTS/CTS is an optional mechanism used by 802.11 devices to reduce frame collisions over the wireless medium by employing control frames exchange (which can be heard by hidden nodes) before sending a data frame. While it sounds like a good idea, some devices do not interoperate very well with each other.

AMPDU aggregation (concatenating several frames into a big frame) is another example of a 802.11 feature covered by Wi-Fi CERTIFICATION, but still, differences in implementation cause some devices not to “honor” the buffer limits advertised by peer devices, and send frames larger than the buffer of the receiving stations. This may lead to continuous data loss and re-transmissions which may also trigger RTS/CTS, which may reduce overall network capacity.

Speakers synchronization

One of the advantages of Wi-Fi over other wireless technologies is the ability to support multiple speakers/end units. However, one of the main difficulties when wirelessly streaming audio to multiple units is achieving synchronization between them.

Analog speakers, wired directly to the audio receiver, take the electrical audio signal transmitted over the speaker wires and reproduce the sound almost immediately (as the electrical signal travels

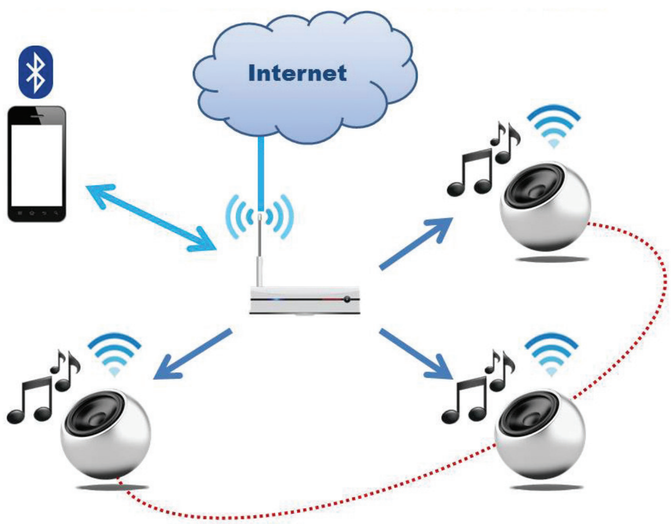

Figure 1: Wireless audio time synchronization multi-speaker system.

through the wire at a speed close to the speed of light).

Since all analog speakers are connected to the same audio receiver, which transmits the signal to all speakers in parallel, all speakers play the audio in almost perfect synchronization. Having no wires, wireless speakers require other means of synchronization.

Typically, the data stream containing the audio samples would be sent per speaker (in a unicast link) and not in broadcast link.

While the samples are buffered in the audio playback buffer, the processors (on different speakers) controlling the playback need to play the specific audio sample at an exact moment in time in near-perfect sync.

Losing synchronization may lead to false or wrong perception of the audio source. Even the slightest delays in audio trick the mind into perceiving the audio source as originating from a different source.

To be able to play the same sample at the same time over multiple speakers, a mechanism for wireless clock synchronization is required.

Typical solutions in the market today use network time protocol (NTP) and continuously send frames over the wireless link from one speaker to another, exchanging time stamps.

Currently, the vast majority of systems are only able to provide audio clock synchronization to an accuracy of a few milliseconds between the receivers and sources and also overload the network.

Other solutions are based on non-widely adopted standards, such as 802.11v.

Wi-Fi / Bluetooth / Bluetooth Smart co-existence

Typically, Wi-Fi audio systems may employ other wireless technologies, such as Bluetooth and/or Bluetooth Smart for added functionality and features.

Bluetooth, for example, is used for A2DP streaming, which is receiving a stereo stream from a mobile phone, or transmitting an audio stream to a wireless headset device.

Bluetooth Smart can be used for provisioning, volume control, etc.

Both Wi-Fi and Bluetooth operate in the unlicensed 2.4-GHz ISM band, and the proximity of the two radios, especially when embedded in a tiny device, has the potential for interference.

Whether using a single- or a dual-antenna solution, two standalone ICs or a combo device, there are challenges to be met with each configuration. A good wireless connectivity solution needs to embed co-existence mechanisms specifically optimized for audio use cases.

Multi-room audio distribution

Multi-room systems enable playing music in multiple rooms, either wired or wireless. These systems consist of two or more speakers, which can be installed in any room at home. The music may be originating from either Internet online streaming services or the user's own digital collection, and controlled usually via a tablet or smartphone using the in-house network. The user can decide whether they wish to play a specific song all across the house or different songs per room.

Implementing the control scheme to distribute the audio over an array of speakers is not an easy task and has its own challenges, but the actual challenge is how to distribute the audio amongst speakers that may be either at the very edge of coverage of the home access point, or totally outside of it.

In-room audio distribution

Typically, when a set of wireless speakers are in the same room and playback starts, one of the speakers in the room will be responsible for distributing the content to other speakers and synchronizing them. This speaker may also need to actively download the content at the same time from an online music streaming service.

The speaker would initiate a unicast stream with each of the speakers in the room, sending the appropriate audio data relevant to that speaker.

While this audio stream on the IP layer is unicast, on the link layer (MAC) all data must traverse through the home access point and "bounce" to the speaker in the room. Each audio frame is therefore transmitted twice, potentially loading and congesting the wireless network.

Some wireless audio vendors solve this issue by using the "master" speaker as a soft AP (wireless access point) while the rest of the speakers act as Wi-Fi station devices. At the same time, the "master" speaker also has to act as a Wi-Fi station device to be able to connect to the home network and pull content from the Internet, for example. This type of solution opens up a new range of new issues, such as latency, routing and network management, speaker discovery issues, etc. For this use-case—a more advanced and efficient networking model is required.

Figure 2: Wireless multi-room audio streaming

Range coverage

While the range of Wi-Fi enabled audio devices is longer than several other wireless technology options, in some deployments and environments, due to structural factors, some rooms might either be with poor Wi-Fi coverage or without coverage at all.

Wireless audio devices with poor coverage, usually communicate with the home access point at low data rates—low data rates are more robust and have longer range than high data rates. When the data rate is lower, the wireless medium is busy, preventing other stations from transmitting at the same time. This lowers the overall network performance; therefore, even if the home network infrastructure is based on high-performance 802.11 devices (such as 802.11ac), the overall network performance will degrade in the event that some devices have poor coverage.

Some wireless audio devices may reside in rooms that have no Wi-Fi coverage at all.

Traditionally, in such cases, it was required to either install more access-points around the house to act as repeaters or to connect the speakers inside those rooms with Ethernet cables. Advanced 802.11 features—such as mesh networking—are able to meet the demands of both scenarios by extending the coverage of the home network and offloading it.

Provisioning and device discovery

Either when initially setting up the system after purchase, or adding a new wireless audio device to an existing system, each device has to be configured to connect to the home access network. Since there is typically no complex human interface on most devices, such as keyboard or even a display, another means of provisioning the device is required.

Some solutions are based on Wi-Fi Protected Setup (WPS), which was meant to provide an easy and secure way for home users to configure keyboard-less devices.

Unfortunately, WPS proved to be insecure, and was not adopted as an industry standard.

Other solutions are based on a given device loading up (from factory defaults) as a soft-AP with an SSID that is distinctive. The user then has to connect his mobile device (phone, tablet or laptop) to the device, open a web page, enter the details of their home network and then re-start the device.

On top of the methods mentioned here, some industry leaders have developed their own wireless provisioning technologies, such as Apple's WAC (Wi-Fi Accessory Configuration), which requires a separate authentication chip.

Once the audio devices are connected with the home network, another mechanism is also required to auto-detect other devices in vicinity. Usually these solutions are based on mDNS (multicast DNS).

Power consumption

A wireless audio device such as a speaker may not always be in use while turned on.

Many home users may not be inclined to power off the device when they are done using it and power it back on each time they would like to listen to music again. When the device is fully powered on but not actually in use, it naturally consumes energy. The host processor is awake (although idle), and the connectivity component is connected to the home access point (transferring no data, but still is connected). In this case, a stand-by mode is required where the host processor may enter a sleep/hibernate state to save power, but would still remain "semi-awake" in the sense that if audio starts streaming to it, it would automatically wake-up and begin playing. The desired behavior, in such a case, is for the connectivity component to remain in connected-idle state and wake the host and system upon audio playback request.

In other cases, even when this is done, there is some traffic on the home network which can cause the host processor to wake up in the event that the connectivity component does not filter or automatically respond to it. Maintaining low standby current consumption is critical as there are legal regulatory constraints requiring specific current consumption in such low-power states.

Integrated solution

While some audio vendors have the resources, capacity and experience to develop and support their own audio framework ecosystem, the vast majority of audio vendors prefer to use pre-integrated solutions. Using a pre-integrated turnkey solution has the following benefits:

- Less money spent on development, testing and verification
- Faster time to market

Choosing the right integrated solution is not a simple task. Decision makers need to take the following into account:

- The level of software and hardware integration between processor, connectivity, audio components
- Key services and features supported
- Supported use cases
- How well the solution was verified
- Pre-certification of specific services
- The customization level, how and to what extent can the solution be customized to meet local requirements
- The level of portability
- Robustness of the solution
- Backwards compatibility with existing ecosystem

WiLink™ 8 device audio features

There are many connectivity challenges in building a robust wireless audio product.

TI offers an integrated Wi-Fi audio solution based on our WiLink 8™ module which works on a variety of platforms, enabling faster time to market and an overall better product.

WiLink 8 modules have best-in-class RF performance with very high sensitivity levels supporting long range and high performance.

Antenna diversity and 2.4-GHz and 5-GHz dual-band wireless connectivity extends the wireless communications range of the WiLink 8 module and allows it to maintain connectivity even in the most congested RF environments. The WiLink 8 devices are able to achieve very high throughput, supporting multiple audio channel distribution, whether by unicast or multicast streams.

WiLink 8 devices incorporate advanced rate management algorithms designed to operate at the harshest environments, guaranteeing audio frames delivery, even when the home network is congested. The vast interoperability and maturity of WiLink 8 solutions ensure that wireless speakers and other connected audio devices will be able to receive and transmit an audio stream from and to practically any device.

WiLink 8 modules have optimized data path, rate management and retry policies, aggregation size control and most importantly multi-role, single-channel shared TX provide the infrastructure for a solution with both low-latency and jitter.

The ultra-precise clock synchronization feature of WiLink 8 devices, with guaranteed clock accuracy drift of less than 20 µsec between any number of devices using any access point, enables high-quality audio synchronization.

The robust Wi-Fi/dual-mode Bluetooth coexistence capabilities of WiLink 8 modules allow products to combine the benefits of both Wi-Fi and Bluetooth. Customers can use Wi-Fi, Bluetooth and Bluetooth Smart all at the same time, providing key advantages over competitive solutions. Additionally, WiLink 8 devices support several provisioning methods to ensure that any new device can be configured quickly and with ease of use (whether using AP provisioning or WAC).

WiLink 8 has outstanding standby current consumption and supports advanced power mode features, such as wake-on-WLAN (WoWLAN) and packet filtering.

TI is adding mesh support for WiLink 8 modules, enabling the following advantages:

- Range extension
- Multi-room audio offload
- Very low-latency solution
- High accuracy in-zone clock synchronization over mesh
- Smarter path selection

Additionally, TI has partnered with StreamUnlimited to offer a complete, pre-integrated hardware and software turnkey solution providing:

- A fully customizable and portable solution
- Advanced multi-room framework
- Support for all major online streaming music services
- AirPlay® / Google Cast

For more information about WiLink 8 devices and our audio solutions, please visit **http://www.ti.com/wilink**.

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