AirModem™: Achieving seamless low power connectivity among IoT devices

White Paper

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Abstract

The rapid emergence of the Internet of Things (IoT) in recent years has created demand for efficient and cost-effective methods of device-to-device connectivity. From cell phones and tablets to automotive features, home appliances and industrial equipment, today's "smart" devices typically communicate with each other via Wi-Fi, Bluetooth, NFC, or proprietary RF. These connectivity approaches require user interaction that is often cumbersome, costly and non-secure. This white paper presents a low cost, simple way to add seamless, secure, low-power connectivity to your product design using state-of-the-art, data-over-sound technology.

Introduction

In today's Internet of Things (IoT) landscape, connected devices have become ubiquitous at home, at work and everywhere in between. Approximately 45% of the world's population owns a smartphone[1], and smart devices such as tablets, speakers, appliances, lighting controllers, and locks are found in many modern-day homes. Similarly, IoT technologies have become a regular feature in many work settings, where multiple connected devices often reside within a common workspace or production area. Manufacturing, energy, retail, healthcare and automotive are among the largest industrial users of smart devices.

It is predicted that in 2020, the commercial, industrial and automotive IoT market will grow to 5.8 billion connected devices, up 21% from 2019, and that revenue from electronic "smart" devices will total $389 billion globally.[2] As increasing numbers of smart devices are introduced into the global marketplace, there is a growing consumer and industry appetite for technologies that offer efficient, seamless, and secure device-to-device connectivity solutions.

Currently, smart devices can connect via existing technologies such as Wi-Fi, Bluetooth, NFC and proprietary RF. However, these technologies present certain problems, including, inefficient device pairing, unreliable connections, security limitations and high costs to support world-wide compatibility. As such, these connectivity options do not present the best solution for certain use cases. New data-sharing solutions are needed that can facilitate seamless, secure, low cost, interoperability and connectivity.

One such solution is AirModem™, which uses "data-over-sound" to provide low cost, low power, seamless device to device and device to multi-device connectivity. AirModem uses the speakers and microphones of existing IoT devices to send and receive data over an acoustic channel. It is ideal for companies interested in adding wireless connectivity functionality to their existing products because it often does not require any additional hardware. Moreover, as a pairing-free, one-to-many medium, AirModem eliminates some of the common data transmission pain points associated with common connectivity solutions.

[1] https://www.bankmycell.com/blog/how-many-phones-are-in-the-world

[2] https://www.gartner.com/en/newsroom/press-releases/2019-08-29-gartner-says-5-8-billion-enterprise-and-automotive-io

Data-over-sound: a path to enhanced connectivity

Many companies are beginning to realize the potential of data-over-sound technology to provide the efficient, seamless, low cost connectivity that is not always practical with today's commonly used connectivity solutions.

AirModem uses data-over-sound technology to help overcome some common pain points of traditional connectivity solutions.

What is data-over sound?

Conceptually, data-over-sound mirrors the way humans communicate. Data is encoded into an acoustic signal, which is then transmitted through the air to a listener. The acoustic signal is received and demodulated by the listening device. The listening device then decodes the signal and extracts the transmitted data. AirModem applies data-over-sound to facilitate connectivity, as illustrated in Figure 1.

Figure 1 Data Over Sound Concept.

Use Cases for AirModem's Data-Over-Sound Technology

Four key use cases for AirModem have emerged, as identified in Table 2. Data-over-sound is the only data communication solution that meets all of the connectivity requirements for each use case; and since it is run-on low-cost processors, such as those of the Cortex-M series, it meets the specific hardware requirements of affordability and power. By providing AirModem SDKs for low cost processors, we have removed a significant obstacle to incorporating data-over-sound into these IoT applications.

USE CASE	CONNECTIVITY REQUIREMENTS
IoT Device Provisioning	➢ Seamless UX and rapid setup ➢ No pairing/configuration ➢ One-to-many ➢ >10m range ➢ Non-line of sight ➢ No additional hardware requirements on router ➢ No additional infrastructure requirements
Proximity Detection	➢ Respects room boundaries ➢ One-to-many ➢ Universal device support
Two-way acoustic NFC	➢ Two-way ➢ Low-cost, low power ➢ Universal device support ➢ Supports industry-standard cryptography
Telemetry in RF-restricted environments	➢ No use of EM spectrum ➢ Up to 100m range ➢ Non-line of sight ➢ Two-way communication ➢ Low data rate

Table 2: Key use cases of AirModem™.

Device Connectivity Solutions Using AirModem

AirModem provides an ideal solution for many applications, particularly those requiring seamless connectivity and minimal human effort. Key application areas incorporate the advantages offered by data-over-sound for device provisioning, proximity and presence detection, two-way acoustics NFC, and telemetry in RF-restricted environments.

Simple Fast IoT Device Provisioning

Provisioning a new smart device with network credentials and functional configurations remains a disproportionately complex process, particularly for headless devices. Although technologies (such as WPS) have been introduced to address this challenge, most require internet support or, in some cases, physical access to the access point itself.

AirModem offers an offline, locally-bounded approach to provisioning and does not require any infrastructure modifications. Credentials are encoded as audio, optionally layered with cryptography for secure scenarios, and broadcast over-the-air to nearby smart devices. Typically, the only hardware purchase requirements for receiving and decoding credentials are a single low-cost processor and an analog or digital MEMS microphone.

AirModem makes provisioning home smart devices simple and fast and can significantly reduce the frustration commonly associated with this task. Additionally, AirModem offers substantial time and cost savings in industrial scenarios, where multiple smart devices may need provisioning on a regular basis.

Problem: Provision IoT appliance to a local Wi-Fi network.

Example: Place your IoT washer machine on your Wi-Fi network

Existing Approach:

1. Download washer machine App
2. Unit powers up with an ad hoc wifi network
3. User connects to ad hoc wifi network with cell phone
4. User shares wifi SSID password for the home network
5. User reboots device

Disadvantages:

- Multi step process
- If there is an error in user data, need to factory reset and begin again

AirModem Approach:

1. Power up new appliance
2. Visit website on your cell phone, enter your wifi credentials and press send

Advantages of Using AirModem:

- Simple and intuitive registration
- Any typos when entering the data can be communicated back to the user as an error message
- No App development for multiple platforms

Proximity and Presence Detection

Acoustic signals respect room boundaries, particularly when signals are transmitted in the near-ultrasonic range. Consequently, there is a growing interest in using near-ultrasonic acoustic beacons for sensing the presence of other devices in a room. Sonar-like beacons can be transmitted from devices at regular intervals, enabling them to be discovered by nearby devices. As an option, AirModem can be configured as a multiple access modulation scheme to support multiple devices within hearing range.

Problem: Share data with a device based on proximity

Example: Museum visitor gets information about the display on a mobile phone

Existing Approach:
Visitor rents a from the museum which streams audio data

Disadvantages:

- Rental device is a vector for passing infection such as Covid-19
- Museum must maintain specialized hardware that is handled and abused by patrons
- Museum must have a charging infrastructure for devices

Method Using AirModem:
Patron enters near display and cell phone browser receives the relevant data which is displayed to the patron on the phone

Advantages of Using AirModem:

- Simple proximity based data exchange
- Utilizes personal existing cell phone
- Enable in app purchases (prints, books, posters etc)
- Possible to keep a detailed logs of the visit on your mobile device
- Control proximity coverage by controlling volume level at the speaker

Two-way acoustic NFC

Acoustic near field communication (NFC) is emerging as an effective solution for enabling peer-to-peer payments and POS devices. Data-over-sound provides a low power, low cost way to achieve these communications. AirModem's two-way full-duplex mode of communication, addresses a critical limitation of NFC by enabling devices to perform challenge-and-response dialogues for secure financial transactions, or for securely sending receipts to a merchant or buyer. What's more, since AirModem is software-defined, it requires no additional hardware.

Problem: Share data from devices to an internet device

Example: Parking meter interaction with a mobile device

Existing Approach:

1. Parking meters need to be tied into cell network
2. Parking meter are interaction is coin based

Disadvantages:

- Rental of cellular network
- Coin based payment is cumbersome

Method Using AirModem:

Motorist visits parking meter and reserves it/pays with AirModem enabled cell phone app

Advantages of Using AirModem:

- No recurring wireless charges
- Parking meters need not be on the network
- All intelligence is on the web app not on the parking meter
- Runs on widely available cell phones

Telemetry in RF-restricted environments

Radio frequency-based communications are sometimes prohibited due to the possible occurrence of sparks or interference with equipment that pre-dates RF regulation. AirModem overcomes these restrictions, allowing the industrial IoT to benefit from wireless communication without limitation.

Features and advantages of AirModem technology

In selecting a connectivity solution, product designers consider factors, such as cost, data rate, and range, as well as complex details related to device support, backwards compatibility, user experience,

and security. They must also consider the technical specifications of the protocol, including the nature of the transfer medium (RF, optical, acoustic), number of required channels, security concerns, or whether both two-way and one-to-many communication is needed. Table 1 presents an overview of these considerations and compares AirModem's features to those of existing alternative connectivity solutions.

	Air Modem	QR	NFC	Blue-tooth	Wi-Fi	Li-Fi	Zigbee 802.15.4	LoRa	Sigfox
Two-way communication	✓			✓	✓	✓	✓	✓	✓
One-to-many broadcast	✓			✓		✓	✓		
Non-line-of-sight transmission	✓			✓	✓		✓	✓	✓
Works in RF-restricted environments	✓	✓	✓			✓			
Zero setup/pairing/ configuration	✓	✓	✓						
Available to application by default	✓	✓							
Low power operation	✓	✓	✓	✓			✓	✓	✓
Can transmit with < $2 worth of electronics	✓	✓	✓	✓			✓		
Can receive with < $2 worth of electronics	✓			✓			✓		
Wireless broadcasts confined to room boundaries	✓	✓	✓						
Transmit over ranges >10m	✓	✓		✓	✓	✓	✓	✓	✓
Can limit the transmission range to <1m	✓	✓	✓	✓					
Supported by dumb media channels and P.A. systems	✓	✓							
Supported by typical mobile devices	✓	✓	✓	✓	✓				
Supported by low-end mobile devices	✓	✓		✓	✓				
Typical usable max data rate	150 bps	3kb	424 kb/s	25 mb/s	70 mb/s	1 gb/s	250 kb/s	50 kb/s	100 b/s
Typical max range	100m	10:1	20cm	100m	50m	10m	100m	10km	40km

Table 1: Feature comparison for AirModem versus alternative connectivity technologies

Although 150 bps may initially seem like a low data rate, typical use cases require only a small number of bytes to be exchanged between the devices. Thus, a complete two-way protocol to be accomplished in just a few seconds. This makes AirModem the perfect solution for a wide variety of applications.

The above comparison is not comprehensive, and each use-case will bring its own specific requirements. Nonetheless, AirModem offers several distinct advantages that make it particularly attractive for many use cases involving low cost processors. These advantages include:

- **Device interoperability:** Data-over-sound is arguably the most device-compatible wireless communication technology available to date. The only hardware requirements —a speaker and microphone— are readily available in mobile phones, voice-controlled devices, and any devices with a speaker. It can be used in any environment, even RF restricted environments such as hospitals, or near RF sensitive electronic equipment.
- **Embedded deployment:** Housed within the easy-to-use audio development platform Audio Weaver™, from DSP Concepts, AirModem is readily deployed across variety of embedded platforms.
- **Seamless UX:** Since data-over-sound requires no pairing or configuration, data transfer is as simple and fast as pressing a button.
- **Physically bounded for enhanced device detection:** Since sound waves remain within room boundaries, particularly in the near ultrasonic range commonly used in data-over-sound, transmissions do not pass between adjoining rooms. This means that AirModem can be used for detecting the presence of a device with room-level granularity.
- **Low or no added hardware costs:** Millions of devices are pre-equipped with the processor, speaker, and microphone required to facilitate seamless data-over-sound transmission. Consequently, data-over-sound functionality can be achieved without costly and time-consuming physical upgrades to existing hardware. If audio I/O is needed, the cost for sender and receiver components is less than $2.
- **Zero power:** The availability of 'wake-on-sound' MEMs microphones [3] enables devices to communicate using data-over-sound, using only minimal battery power (< 10 µA) between communications.
- **Low CPU resources:** A typical install requires only 25% of an M4 processor when enabled.

AirModem Performance Advantages

AirModem has been tested in a variety of environments, including cars, reflective rooms (such as tiled bathrooms), large open rooms, and even outdoor environments. Additionally, each AirModem release

[3] e.g. Vesper VM1010

is validated against broad selection of real world situations such as cocktail party noise, barking dogs, clanking glasses and additive white Gaussian noise.

AirModem employs modulation schemes that are designed to be robust in the highly reverberant and noisy environments where consumer products often reside. State-of-the-art error correcting codes add an additional layer of robustness. Further, all data is verified using a CRC to ensure perfect packet reception. AirModem's Packet structure is shown in Figure 2

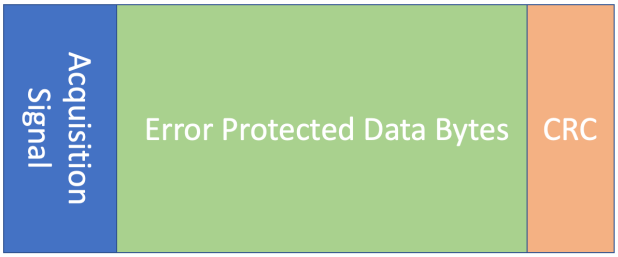

Figure 2: The AirModem Data Packet Structure.

AirModem is flexible and can be configured to suit the customer's requirements. By changing the carrier frequency, AirModem can be configured as an audible signal or, if the hardware supports it, as an inaudible ultrasonic signal. Furthermore, by adjusting parameters within the forward error correction, trade-offs can be made between data rate, transmission range, and noise performance to suit the customer's end application.

The AirModem spectrum occupies only 5 KHz of bandwidth, allowing the simultaneous transmission of speech, music or sounds. This 'watermarking' can be used to prompt or instruct the user as the digital data is sent.

Audio Weaver: AirModem meets your IoT products

Embedded as an easy-to-use Audio Weaver module, AirModem is easy to apply to product designs. With Audio Weaver integration, AirModem is processor agnostic, allowing product designers and engineers to integrate, invent and fine tune their data-over-sound applications on a broad range of processors. This "Design Once, Deploy Everywhere" approach allows product teams to incorporate AirModem across product families with little additional work. Audio Weaver is supported on a variety of low-cost processors, and its real-time MIPS and memory profiling feature empowers system architects to make fast, reliable decisions about processor selection.

AirModem can be readily deployed across variety of platforms, including:

Web Assembly: AirModem technology meets your web application

AirModem is also available as a WebAssembly (WASM) module. WebAssembly is a technology which allows native execution of real-time code in a browser environment. Using AirModem's WASM module, web developers can integrate data-over-sound into app-less mobile deployments served off of a webserver. This makes maintaining and deploying data-over-sound applications platform agnostic, with a single application able to run on IOS, Android, Linux, Windows and MacOS devices.

Summary

This white paper reviewed AirModem data-over-sound technology as a low cost, seamless, device-to-device connectivity solution for today's smart devices. Used at home or in industrial settings, this technology facilitates a seamless, low-cost solution for device provisioning, or RF-free telemetry in general. And, since most IoT devices come pre-equipped with microphones, billions of existing devices are already equipped with the hardware required for data-over-sound transmissions. Add to that, the emergence of zero-power microphones, and AirModem has the potential to provide an extremely low power, 'always connected', device-to-device data transfer solution.

We have developed the AirModem for low cost processors, such as the Cortex-M33 and Cortex-M4. The high-performance DSP features on these chips allow for high sample rate audio processing without the need for hardware acceleration, enabling the encoding and decoding of ultrasonic sound transmissions. As an embedded feature in Audio Weaver, AirModem makes it easy for device manufacturers and developers who wish to take advantage of this novel connectivity solution.

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