

A COLLOCATED APPROACH FOR COEXISTENCE RESOLUTION IN WIRELESS HOME NETWORKING

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ABSTRACT: In a home networking environment, where more than one radio devices use 2.4GHz band within a certain distance may result in a significant interference. This research mainly focused on particular technologies that operate in 2.4GHz radio channel analysing the fact that the Bluetooth and Wi-Fi radio operation in a wireless network environment may create interference and may deliver poor throughput. We also focused on the importance of Bluetooth as a wireless technology and its potentiality of adoption in a wireless home networking environment. Therefore, the paper intends to outline an approach of coexistence for Bluetooth and Wi-Fi technologies in a given wireless network. This research combines some ideas of coexistence where we can mitigate the interference to improve throughput and thus the network performance. The mechanism proposed a collocation approach for Bluetooth (BT) and Wi-Fi where the radios will reside in a single form factor. In this approach, the radios are collocated in a single device that utilizes Adaptive Frequency Hopping (AFH), Medium Access Control (MAC) level switching and Driver level switching in its respective architecture levels, enabling simultaneous operation between Wi-Fi and Bluetooth devices. The device Operating System (OS) controls the operations and throughout the process, interference mitigation performed in just one device rather than every single device in the network. Although the collocated approach is a suitable solution for interference mitigation, there are limitations in its implementation and compatibility with other technologies. Further research would resolve that issues.

1. INTRODUCTION

Bluetooth is a short-range radio solution for small devices to connect themselves wirelessly and it is capable of eliminating cable clutters using its globally available Industrial Scientific Medical (ISM) band. The Bluetooth or in other word IEEE (Institute of Electrical and Electronics Engineers) 802.15 specification is designed to provide wireless connectivity to portable and small devices using a simple wireless technology. Low-cost, compatibility, universality made this technology globally popular as an ad-hoc wireless network solution.

At present, the most widely used wireless technologies are IEEE 802.1x radio solutions. IEEE standardised the Bluetooth technology that originally developed by the Bluetooth Special Interest Group (SIG) in 1998. Since then, other wireless technologies have invented and developed alongside the Bluetooth in particular 802.11b or Wi-Fi. Some features of Bluetooth made it unique in number of areas and most important of them is it's 2.4 GHz ISM band that are available licence free globally. Bluetooth can reside as very simple and compact form factor without using much power and space. This capability is very important for small devices that have limited power supply.

Technology of such convenience has wide appeals for deployment in home networking environments where users connect devices and peripherals with cables. Bluetooth's capability of replacing cable clutters from electronic devices mean a substantial increase in adoption expected in the future. Adoption in home networking depends on many factors and interference is one of these factors. Because in a wireless home networking environment it is expected that one or more wireless technologies will reside on a single or multiple form of networks with other Radio Frequency (RF) that operate in the same 2.4 GHz band, chances of collision during transmission/operation are likely.

This research addresses an important problem encountered in adopting Bluetooth in wireless home networks. Here, the term "wireless home network" refers to the scenario of connecting multiple wireless devices used in common household with or without Bluetooth radio existence. The extent to which Bluetooth technology adopted in home network defines its acceptability and capability for coexistence and simultaneous operations with other common wireless technologies. In this regard, we will discuss and analyse interferences and compatibility of the Bluetooth technology with Wi-Fi or IEEE 802.11b radio standard. The IEEE 802.11b standard is a Wireless Local Area Network (WLAN)

specification that provides high throughput and secure network interface for Local Area Network (LAN) access. This technology is almost identical to that of Bluetooth.

The coexistence issue is an important research problem for engineers and manufacturers of wireless networking technologies. This research tries to address the way of eliminating or reducing interferences among multiple wireless technologies as well as to serve the goal of boosting adoption of Bluetooth in home networks.

2. REVIEW OF COEXISTENCE MITIGATION APPROACHES

Researches have conducted in recent years to develop viable solutions for coexistence of RF (Radio Frequency) enabled devices. The adoption of Bluetooth devices in home network is highly influenced by the progress of related studies. Unless a better solution to embed these technologies found, it would be difficult to imagine the coexistence of multiple RF technologies. Market leader like Intel [INT05] has already incorporated their coexistence solution of Bluetooth and Wi-Fi (802.11b) in their products, called "Intel® Wireless Coexistence System". In this section, we will try to examine the existing approaches and critically evaluate their ability to improve coexistence. These approaches include:

1. Simple device collocation with no coexistence mechanism;
2. Switching between two protocols;
3. Restricted or adaptive band hopping for Bluetooth devices;
4. System-level approaches covering the entire wireless sub-system and many of the above techniques.

2.1. Collocation without coexistence mechanism

One of the biggest developer and researcher in wireless networking, Mobilian [MOB01] describes the approach as a simple integration of two wireless technologies residing in a single form factor without any attempt to avoid the potential interferences. For example, a device with Bluetooth enabled and also Wi-Fi installed, can operate simultaneously where Bluetooth connects a headphone and Wi-Fi connects with an access point. In this usage model, no coexistence mechanism is used. Figure 1 illustrates the collocation approach that operates without coexistence mechanism.

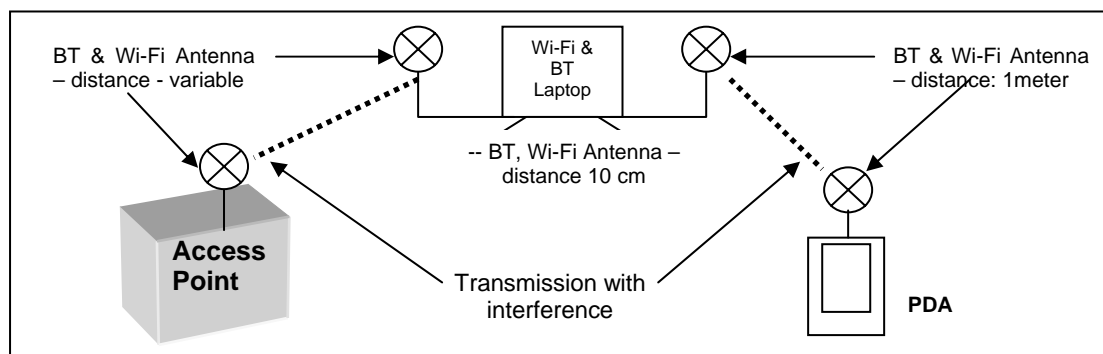


Figure 1: Usage model of collocation without coexistence mechanism

Here, using Bluetooth and Wi-Fi in this collocating model without any coexistence mechanism created a significant interference [MOB01]. The Laptop use Wi-Fi and Bluetooth radio collocation approach but no coexistence mechanism implemented. Therefore, performance in both protocols degraded because of interference in Bluetooth and Wi-Fi channels.

2.2. Driver level switching between Wi-Fi and Bluetooth

This is a time division approach, where each Bluetooth and Wi-Fi radio is operational for a certain period. Both radios accommodate the radio frequency area in the network by switching the power on and off so they can access each other without interference. Mobilian [MOB01] defines various forms of driver-level switching include:

Dual-mode radio switching: The system works as a switch where one radio turned off when another one is still operational (e.g., placing Bluetooth in park/hold mode or Wi-Fi in power-save mode). The mechanism works with either signalling or no-signalling approaches between radios.

Driver-level switching: This scenario is almost similar to the previous one. Nevertheless, here many type of techniques that used and controlled at the driver level. That includes User-dependent switching, discriminatory switching, successful-transmission switching, statistical switching, and time-delay switching.

Analysis: Unfortunately, these solutions cannot provide universal support of a home network. In a wireless home network, there will be voice and data transmission over a Bluetooth wireless connection. Neither “with signalling” nor “without signalling” supports Bluetooth Synchronous Connection Oriented (SCO) links (this is the link that Bluetooth uses to transfer voice over a wireless network). Voice over the Bluetooth network is supposed to be real-time or near real-time. Because of the time delay of the mechanism, voice will not transferred in real-time. Bluetooth SCO would interrupted by Wi-Fi active connection. This performance is not sufficient for a voice transmission. Simultaneous operations of Bluetooth and Wi-Fi devices are nearly impossible in this mechanism.

Host operating systems have variable latencies because of the concurrency of many processes and activities in a typical system. When any interruption occurs in the Baseband of the radio, the OS executes it in the background or along with other processes. In this manner, it is possible to have a long queue that might result in delay of the Baseband interrupt handling. Because of this varied latency, when the operating system processes a request and passes it to the driver, the driver is not able to determine the proper response. The reason is that it does not know the time differences between the requests. The driver might consider a request as a one (1)-millisecond delay whereas it is actually a one (1)-millisecond second delay. In a dynamic network environment, it is a huge timing problem where Bluetooth and Wi-Fi both operate in a microsecond interval. Therefore, the Baseband is not ready for this approach to adopt and further researches needed to enable this mechanism to implement properly.

2.3. Adaptive Frequency Hopping (AFH)

This is a frequency-division approach that was developed by Bluetooth Special Interest Group (SIG) and IEEE 802.15.2 Coexistence Task Group (CTG). IEEE [IEEE01] defines the approach:

“Adaptive frequency hopping (AFH) is a non-collaborative mechanism that enables the coexistence of IEEE 802.15.1 (Bluetooth) devices with frequency static devices in the 2.4 GHz ISM band, such as IEEE 802.11b (WLAN).”

This mechanism dynamically changes the frequency hopping sequence in order to avoid or mitigate the interference seen by the 802.15 device and the technique uses a certain portion of the 2.4 GHz channel.

Analysis: Adaptive hopping possesses a good chance of adoption in a mixed Bluetooth and Wi-Fi environment. We may expect regulated timing for appropriate processes and maintenance of the adaptive hopping algorithm throughout the transmission. To ensure the integrity of adaptive hopping, the timeliness of the regulatory process is very important. In order to achieve this, the process in the transmission should be relatively quick. As soon as the ratification of timing ensured, Bluetooth adaptive hopping will provide an excellent coexistence solution in environments with two or fewer Bluetooth PicoNets and no overlapping Wi-Fi networks.

2.4. MAC-level Switching

Leading research group for RF and microwave, RFDESIGN [Jef04] defines Medium Access Control or MAC level switching as,

“The most effective means to providing performance levels approaching no-interference scenarios is MAC-level switching. MAC-level switching is a collaborative technique, which exchanges information between the two protocols at the MAC level, and manage transmits and receive operations.”

MAC-level switching takes place in the Baseband and it is able to switch between protocols at a much faster rate than driver-level approaches. The technique does not suffer from transmitting signals into incoming receptions, Bluetooth polling or operating system latency.

Analysis: MAC-Level switching works in the same functionality as driver level switching. Compared to driver level switching, MAC-Level switching has much faster rate of transmission and has predictable latency. In addition to that, it has the capability to mitigate many of the interference factors that driver-level switching cannot. MAC-level does not have the weak characteristics of other mechanisms, like transmitting signals into incoming receptions, Bluetooth polling, or operating system latency. These features make MAC-level switching as a suitable solution to establish effective SCO link in a Bluetooth enabled wireless network. However, still like many other approaches, it does have some weaknesses. One of them is adjacent-channel interference and another one is performance degradation. A major limitation of this mechanism is, a long development cycle time relative to a driver-level switching approach. If we implement this mechanism in a small system with driver-level switching approach, an increased development life cycle predicted.

3. PROPOSED COEXISTENCE MECHANISM

In the last section, we have analysed different mechanisms and approaches as the solutions for similar problem. As we analysed, the solutions seems unreliable in some extent where the Bluetooth radio face interferences with other 802.1x enabled devices. In the Driver level switching, the devices are communicating together in a slow and static way of transmission. Switching is not a definite solution for coexistence. In switching, devices lose their throughput and thus the network channels. When we think of a PicoNet, the Wi-Fi device in connecting to a Bluetooth device, then the “leaving network without signalling” will break the PicoNet.

When it comes to Adaptive Hopping, researchers are still trying to implement a successful hopping mechanism. There are many difficulties to overcome in this area. They need to change four major sector of Bluetooth specification. These four interrelated key areas need to be changed: the hopping kernel, definition of behaviour during all modes of operation, link control messages, and a bad channel determination algorithm. In this mechanism, the security is a major issue to address. In Adaptive hopping, the device hops around 15 1-MHz channels instead of 79 1-MHz channels in the 2.4 ISM. Here, the security has compromised. The reason is that the hopping minimized significantly and two devices are sharing the same channels.

3.1. Collocated Approach with Coexistence Mechanism

3.1.1. The Usage Model

The usage model for Bluetooth network is Personal Area Network (PAN) and WLAN for the Wi-Fi as we discussed before. Some coexistence issues can be resolved by analysing the usage model for the proposed approach. Here, an approach described that enables coexistence without losing the essential features of a suitable wireless network. The mechanism would work simultaneously between peripheral and devices no matter how the user is configuring the network. A printer with Bluetooth will work without any interferences and the access point would work with its own bandwidth when communicating with Bluetooth at the same time.

The main idea is to implement a mechanism in the home network that will work an “on demand” basis on a device that supports all of adaptive hopping, driver level switching and collocation to provide dynamic networking. In this approach, the entire system divided into sub-systems where every sub-system implements an existing mechanism that will work without any interference. Figure 2 illustrates this usage model of an operational coexistence mechanism.

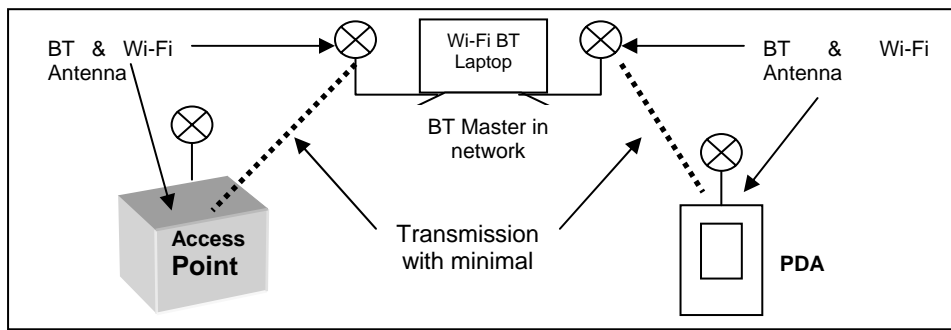


Figure 2: Collocation Approach with Coexistence Mechanism

Here, we see in a simulated home network, a laptop computer with Wi-Fi and other Bluetooth devices can work with other devices with different technologies simultaneously. In this approach, we can expect standard throughput and dynamic transmission. This mechanism will work with driver-level switching, adaptive frequency hopping and/or MAC-level switching. When this approach collocated and uses these mechanisms in a master device on a Bluetooth home network, the transmission between Wi-Fi and Bluetooth will go through just one device isolating other devices from network jamming or disconnection.

In this usage model, collocated Wi-Fi and Bluetooth devices communicate each other in a multitude of mechanisms. When the applications on the host (Bluetooth master) device need to use or communicate to another Bluetooth device, it does not need Adaptive Frequency Hopping (AFH), because there is no interference between Bluetooth devices. Nevertheless, when it comes to Bluetooth to Wi-Fi transmission in the same network, we can use Adaptive Frequency Hopping, MAC-level switching and Driver-level switching in a priority basis. For example, using AFH in a printing command in an application where throughput is not a big issue. Currently, if we consider the scenario of a mobile phone with Bluetooth to communicate a Wi-Fi laptop, the problem of interference will occur. In this particular scenario, we may use MAC-level switching on the Bluetooth master from where the two devices will communicate. Figure 3 illustrates many possible events that may take place in a wireless home network while coexistence mechanism implemented.

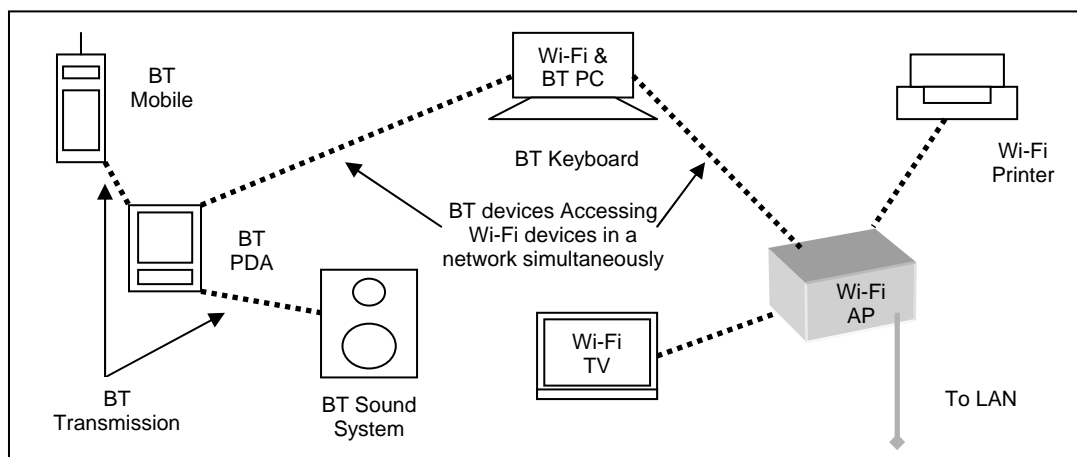


Figure 3: Bluetooth and Wi-Fi collocation usage model

Here, we can see the Bluetooth devices are communicating with Wi-Fi devices simultaneously with minimal or no interferences. Bluetooth devices are connecting together creating a PicoNet and communicating with one or more Wi-Fi devices simultaneously where every transmission is happening via the collocated device, that is, the PC (Personal Computer) with an operating system. If the Bluetooth PDA (Personal Digital Assistant) requests the Wi-Fi device to copy a file from the LAN, that will go through the Wi-Fi Bluetooth collocated PC. In the collocated PC, the Wi-Fi device will execute the command and file transfer will be in process. Here, the MAC level switching will switch in

a rate faster than Driver-level switching and file transfer will be done without much interference or throughput degradation. In this way, we may reduce the throughput loss in SCO and maximizing voice transmission quality in the wireless network.

In this model we may deploy the mechanism in just one device OS not more than that. If network contains more than one device with OS then just one of them may be used.

3.1.2. The Architecture

This approach should provide a simultaneous, full-standard compliant radio communication with very low rate of performance degradation. The user in a home network should enjoy a performance based on dynamic wireless communication no matter what version of Wi-Fi or Bluetooth devices they are using. Any device in the home network would work no matter the distance, device major, application format the devices may have. For example, a MAC-level switching in the Baseband will just switch the Bluetooth device request in a very fast rate and data transfer will not be affected by the format or distance. Figure 4 demonstrate a collocated device with coexistence mechanism.

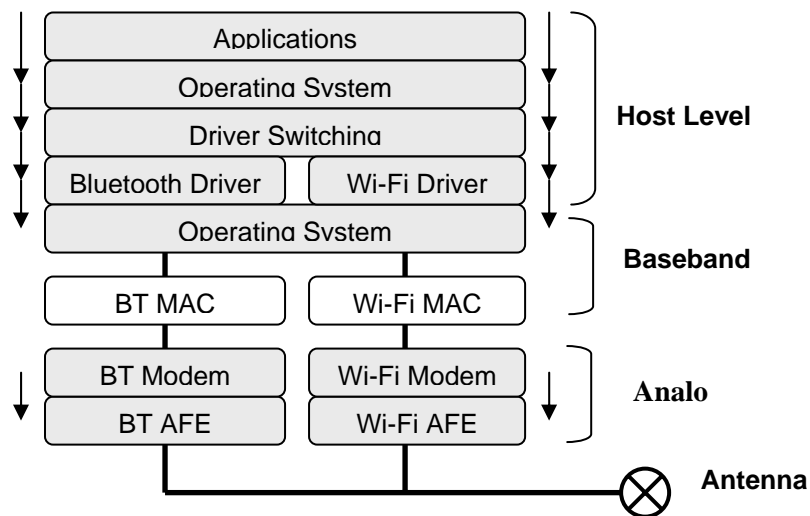


Figure 4: Collocated devices with coexistence mechanism

Here, simultaneous operation is possible with the help of devices with Bluetooth and Wi-Fi technology. In the design methodology, we may use the best technique that may suit the particular need of a device type. Network environment and required usage model will decide the switching between technique/s and mechanism/s. For example, an application requesting a file transfer may be applicable to the MAC-level switching and Adaptive Hopping. In this way, large file will be transferred in a secure way without interference. Another example can be the voice transmission between Bluetooth and Wi-Fi devices. In this scenario, the devices must use the MAC-level switching to avoid interference and to establish an effective SCO traffic in between.

CONCLUSIONS

Coexistence with other technologies presents us a broader view of networking. In particular, Bluetooth and Wi-Fi coexistence with simultaneous operations is a desirable goal as both technologies are expected to grow rapidly over the next few years. This scenario demands us eliminate the coexistence obstacles using effective collocation mechanisms with usage models and simultaneous operation mechanisms. Although the current models have limitations, they have the potentiality for future development. As we see in the coexistence approach with coexistence mechanism, the PicoNet usage model is a solution for the scenario at present. Similarly, a Scatternet model may develop in the future to make the network more useful and robust. Future researches may also include device independent coexistence mechanisms so that we may be able to use any Bluetooth devices with any other related wireless devices in a home network. All the mechanisms that are explained and critically discussed comprise the future of the next generation approaches that might be able to replace existing mechanisms providing viable solutions. Such effective mechanisms will become increasingly important for Bluetooth and other emerging wireless radio standards.

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