Video over Wireless Bluetooth™ Technology

Ben Smith
(bjs100@ecs.soton.ac.uk)
Department of Electronics and Computer Science
University of Southampton

Abstract

With the advent of Bluetooth wireless technology it is now possible to have mobile video and voice communication. However, mobile radio communication, such as Bluetooth, is not entirely suitable for current video encoding methods due to its varying signal strength. These compression methods need to be made more resilient to errors in order for them to be able to operate as part of a wireless communications device. This paper looks at the technology behind wireless video over Bluetooth and provides a solution to the current problems faced, so that they may be overcome in the future.

Keywords

Multimedia networking, wireless networks, Bluetooth, mobile multimedia, MPEG video compression

Introduction

Video and audio streaming is an important aspect of a wireless network. Using Bluetooth allows mobile users the ability to send and receive video streams on small, compact devices. However, the variability involved with radio transmission devices, such as Bluetooth, add to the existing problem of reducing large amounts of 'raw' audio and video data to be transmitted over a limited bandwidth. This is currently achieved by using video and audio compression techniques. However, these video codec's (***co****mpressor/****dec****ompressor*) were not originally designed for transmission mediums that have such a high degree of possible error rates. These errors may be due to a number of reasons including out-of-range devices, interference with other Bluetooth devices and interference with other external sources.

Bluetooth is not the only technology currently available for wireless networking; there is the Wireless LAN IEEE 802.11 standard and the Infra-Red connection (IrDA) standard. This paper discusses only Bluetooth as a means of wireless video transmission. However, the two other wireless technologies mentioned have benefits and disadvantages over Bluetooth. Infrared Data Association (IrDA) is a point-to-point, narrow angle (30° cone), ad-hoc data transmission standard designed to operate over a distance of 0 to 1 metres and at speeds of 9600 bit/s to 16 Mbit/s [1]. The wireless networking standard IEE 802.11 uses the same radio frequency band as Bluetooth and has a bandwidth of 11 Mbit/s.

Both IrDA and IEEE 802.11 wireless standards have a higher bandwidth than Bluetooth, making them more appropriate for transmission of high volumes of data such as video. Using either of these technologies instead of Bluetooth would result in higher quality video as the compression rates required are lower due to the larger bandwidth available. Yet Bluetooth has distinct advantages that make it the preferred choice in some applications. In certain situations the benefits outweigh the costs associated with a reduced bandwidth. For example IrDA requires direct line-of-sight connections between devices and the range is only up to one metre. Bluetooth uses radio frequency so has the advantages that it can go through walls and has a range of up to ten metres.

In comparison with the 802.11 wireless standard, Bluetooth is cheaper and smaller making it ideal for small, light, mobile devices including PDA's, mobile phones and laptops. In these examples the small size and weight of Bluetooth makes it preferable to the user over any benefits gained from increased bandwidth. The manufacturers of mobile devices that require wireless networking between products will be interested in the lower unit cost of Bluetooth and the tiny size of the hardware required. For these reasons wireless Bluetooth video streaming will be popular and this paper looks at how the drawback of low bandwidth can be overcome to provide this service.

Background

Bluetooth

With the current trend towards mobile multimedia and wireless networks, Bluetooth provides a ‘no-wires’ connection between a huge variety of electronic devices including pc’s, printers, mobile phones, PDA’s, laptops and many more. The name Bluetooth comes from the 10th Century King, Harald Blatand, who united Denmark and Norway. Blue-Tooth is the English translation of his name.

Bluetooth™

“Bluetooth is the official name of a specification that has become the fastest growing technology standard ever. Put simply, Bluetooth is a specification for wireless technology, a global standard that lets devices communicate with each other using a secure radio frequency.” [2]

Bluetooth is the specification for a short-range, around 10 metres[3], network between two devices that has backing from wireless giants Ericson, Motorola and Nokia, along with other companies including Intel, Microsoft, 3Com, Lucent, IBM, Toshiba and around 2000 others. [4] The 1998 partnership of the originators has evolved to the Bluetooth Special Interest Group (SIG) which currently supervises the Bluetooth specification. [5]

The benefits of Bluetooth technology mean wireless mobile connections between devices providing ad-hoc networking. Hence Bluetooth radio-equipped devices will be able to establish connections to other devices as soon as they are in range, without user intervention. When two Bluetooth devices are in range, they can link to form a mini-network called a piconet. The technology supports point-to-point and point-to-multipoint connections, so several piconets can be established and linked at will. In total, up to eight users or Bluetooth devices can form a piconet. Up to ten separate piconets can exist within the range of a device which is known as a scatter-net.

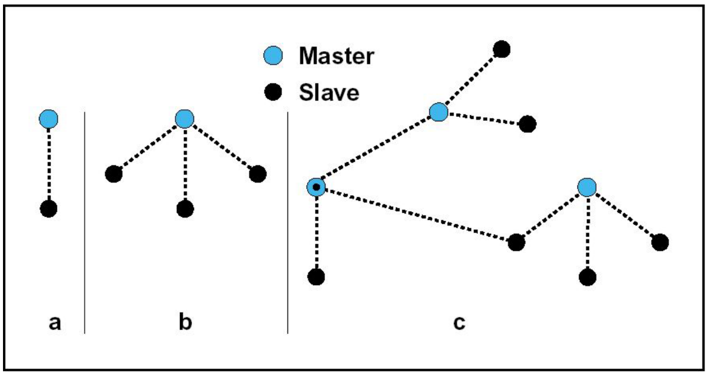

Fig 1 Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet (c)

Within a piconet a Bluetooth unit can either take on a master or slave role, each piconet must have one master (there must always be one) and up to seven slave devices. However, any Bluetooth device can become a master in a piconet. The connection point between two piconets consists of a Bluetooth device that is a member of both groups. This device can act as a slave in both or a master in one, but not a master in both. [6]

Within each piconet, services can be offered to the users with minimal configuration requirements. For example, a roaming user with their Bluetooth-enabled laptop could send a document to an enabled conference room printer without any setup needed by the user. Bluetooth provides excellent support for high levels of mobility through the use of ad-hoc connections. Plus the ability to extend is easily available since new devices automatically join existing piconets once within their range. This removes the need for physically wired links between two points.

Bluetooth connection details

To combat interference and comply with FCC regulations, Bluetooth uses a spread-spectrum technique called frequency hopping rather than transmitting over a single fixed frequency. Bluetooth operates in the 2.4 GHz ISM (Industrial Scientific Medicine) band. In a vast majority of countries around the world the range of this frequency band is 2400 - 2483.5 MHz. Some countries have, however, national limitations in the frequency range. In order to comply with these national limitations, special frequency hopping algorithms have been specified. [5] The 2.4 GHz ISM frequency is the same range as that used by the wireless networking standard IEEE 802.11. In comparison, Bluetooth is lower powered and has a lower bandwidth than 802.11 (1Mbit/s for Bluetooth compared with 11Mbit/s). This means it has shorter data packets and faster frequency hopping.

Unfortunately this frequency band is shared by a number of other devices including microwaves, garage door openers, cordless phones and baby alarms. These all produce unpredictable interference to a Bluetooth device or piconet. The frequency hopping of Bluetooth must therefore transmit data in successive small packets on different frequencies. This enables interference to be avoided on a particular fixed frequency and data packet loss to be minimised.

Bluetooth devices use discrete 1Mhz channels within the 2.4Ghz band resulting in 79 distinct carrier frequencies (RF channels) starting at 2.402Ghz. The total size of the band in the US and Europe is 84.5 MHz, minus a guard band at each end of the spectrum to comply with out-of-band regulations. Two Bluetooth devices connected to each other must use a common frequency hopping sequence to ensure that they stay synchronised.

"The hopping sequence is unique for the piconet and is determined by the Bluetooth device address of the master; the phase in the hopping sequence is determined by the Bluetooth clock of the master." [5]

One of ten different hopping sequences can be chosen and once the devices initially synchronise they can then jump to a new frequency and still communicate. Bluetooth has 1,600 frequency hops per second and a 625 microseconds transmission period at a particular frequency, resulting in Bluetooth being almost impenetrable to interference.

Bluetooth data-rate

The data rate of a Bluetooth connection is given as 1Mbit/s and three types of data links between two devices or nodes are specified, the details of the data links are given below.

"one asynchronous data channel, up to three simultaneous voice channels or a channel that supports both asynchronous data and synchronous voice. Asynchronous data channels can deliver up to 432.6Kbit/s symmetric, or 721Kbit/s asymmetric with up to 57.6Kbit/s in the return direction, while voice channels provide 64Kbit/s in each direction." [3]

Bluetooth wastes over 27% of the available bandwidth on acknowledgement and frequency hopping, resulting in a 721Kbit/s maximum data rate. [7]

LSB 72	54	0 - 2745 MSB
ACCESS CODE	HEADER	PAYLOAD

Fig 2.Standard data packet format

Video Compression

The aim of video compression is to remove redundant information from a digitised video sequence. This can be achieved in a number of ways: reducing colour nuances within the image; reducing the colour resolution with respect to the prevailing light intensity; removing small, invisible parts of the picture and by disregarding the parts of the picture that remain unchanged from the previous frame. All of these techniques are based on the way the human brain and eyes work together to form images. As a result these subtle reductions account for a significant compression in file size and lower bit-rate, yet have little or no adverse effects on the visual quality. [8]

MPEG-4 in detail

"MPEG (formally ISO/IEC JTC1/SC29/WG11) is a group of experts dedicated to the development of standards for digital audio and video. Its membership has very broad industry coverage and is very large." [9]

MPEG-4 is one of the newest video compression techniques and allows much lower compression ratios than the previous MPEG-2 which is the quality of video seen on DVD. This means that MPEG-4 is ideally suited to low bandwidth applications, exactly matching the requirements for video over a wireless Bluetooth network. The use of wireless video over Bluetooth is not strictly limited to using the MPEG-4 video compression technique, there are many others to choose from. For this paper only MPEG-4 is used in detail to provide one possible solution to the problem of video compression, since it matches the requirements by the ability of having very low bit-rates. A wide coverage of the range of different video compression techniques for streaming video is beyond the scope of this paper.

MPEG-4 provides three modes for encoding an input which are shown in figure 3 below, these are namely:

1. ***Intra*-frame** (I-frame) is encoded independently of any other frame and can be constructed without reference to any other frames
2. ***Predicted*-frame** (P-frame) is predicted (using motion compensation) based on another previously decoded I-frame
3. ***Bidirectional Interpolated*-frame** (B-frame) is predicted based on past as well as future frames

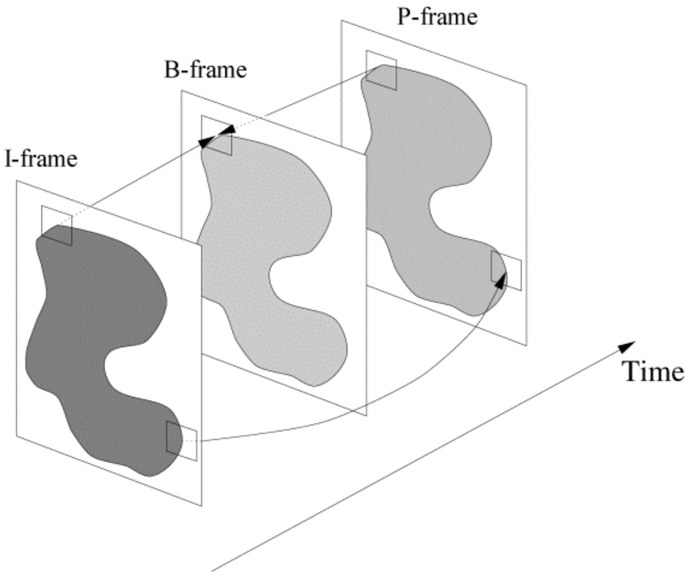

Fig 3.the three modes of frame encoding

MPEG-4 uses motion vectors between frames to encode temporal redundancy and the discrete cosine transform (DCT) to encode spatial redundancy. This is then followed by entropy (or run-length) encoding. The result of this motion encoding scheme is that the I-frame is used to enable reconstruction of all following B or P frames (until the next I-frame). However, as past and sometimes future frames are used to create the next, this means that errors occur if any information is lost. Although it does produce massive savings in the bit-rate required.

Video over Bluetooth

A current challenge for video over a wireless link, using devices such as Bluetooth, is the high degree of variability in the radio signal strength meaning unreliable connections between devices. When sending video using Bluetooth connections, these unreliable connections can cause errors which result in huge defects in the quality of the image received.

Figure 4 on the right shows an example of error artefacts caused by a loss in some of the transmitted video stream data. The reason for these errors are due to the way in which the video is encoded, where only the ‘difference’ between successive video frames is transmitted to reduce bandwidth requirements. If the initial full I-frame is unsuccessfully sent, then any following B or P frames cannot be correctly displayed. This leads to video artefacts such as incorrect blocks in the image. Also, if information is lost about moving objects, these objects can appear ‘floating’ in the video for a few seconds before being corrected.

Fig. 4 MPEG-4 video artefacts

The MPEG-4 video compression standard incorporates several error resilience tools to enable error detection, containment and concealment. These are powerful source-coding techniques for combating bit errors when they occur at rates less than 10^{-3} [10]. However, present-day wireless Bluetooth data connections can have much higher bit error rates (BER). MPEG-4 has a built-in packet technique where several macroblocks (a 16x16 pixel block) are grouped together such that there is no data dependency on the previous packet which helps in localising the errors. [11] To recover from transmission errors, full video frames (intra-frames) without motion prediction must be sent at regular intervals. However, this reduces the compression ratio as sending an increased number of full I-frames requires more bandwidth than transmitting the video scene ‘differences’ and is not an ideal solution to the problem. Yet if the number of I-frames to be sent is reduced there will be a longer interval between two I-frames meaning any artefacts present will appear for longer. This can produce a worse video for the receiver than a lower bit-rate video encoded with a higher number of I-frames.

Error Correction

The typical way of reducing errors when sending data over an unreliable medium is by using error correction. The benefit of this is that problems with the encoded video can be identified and action taken to rectify the problems. The cost is that available bandwidth for useful data transmission, in this case encoded video, is reduced to provide space for the error correction data. Forward Error Correction (FEC) is commonly used to decrease losses when data is transmitted over ‘noisy’ channels such as wireless networks. The overhead is linear to the number of errors it can correct. This means that a very reliable video stream has much lower bandwidth available for compression, hence the quality will be much lower. The use of error correction and the costs involved with the technique are outlined in the following statement.

“The simplest solution for protecting the video information is to use powerful error-correction coding, in order to improve the robustness against transmission errors. However, this technique has some disadvantages, since strong error correction can severely reduce the available bitrate for the video codec and reduce the video quality. If the error correction scheme is designed to cope with short periods of total signal loss, then the error correction can add significant delay to the video system, which may cause the video to appear jerky, and may lead to the loss of synchronisation with the associated audio information.” [12]

Current Research

Research is currently in progress to produce an optimum solution to this problem using a number of different techniques. The idea is to use a video encoder and transport control software that can dynamically respond to the current conditions of the wireless connection between the Bluetooth devices. [13] The aim of this research is outlined below.

“The goal is to gain the desired protocol responsiveness that deals with the frequent unexpected changes in grades of service. The air medium and the mobility support expected of both last hop wireless internet and ad-hoc multi-hop wireless networks requires careful and specialized higher layer protocols for congestion control and QoS support. The ones developed for wired networks fail when put to work in a wireless environment.” [14]

Intelligent Video Bit-rate Control

The need for an Intelligent Video Bit-rate Control system has been given and to implement it would require a protocol that can extend the MPEG-4 video codec to achieve the aims. To begin with when using a streamed video, a low level of error detection must be employed so that if the client receiving the compressed video stream detects an error then it can signal this error to the sender and appropriate action taken. In this case the bit-rate of the video can be lowered by the encoder, allowing error correction to increase and the lost data to be re-sent. This ensures the overall data-rate remains at a constant level to match the bandwidth of the Bluetooth connection.

When the signal strength is poor, a more robust but lower bit-rate modulation scheme is used. However when the signal strength is strong, if for example the mobile receiver is close to the transmitter, the transceiver can switch to a higher-order modulation scheme, which supports a significantly higher bit-rate, providing for higher quality video. This technique is given in detail in the following statement.

"Multimedia applications are sensitive to lost packets, delayed packets and jitter. RTP defines how loss and jitter should be estimated. Their monitoring is performed along the end-to-end path and a feedback packet informs the server periodically. The server uses this past interval to adjust its future sending rate. In essence, the underlying assumption is that the near future network response is anticipated to be similar to that experienced in the near past. QoS information is therefore very time-sensitive. Another realization related to the feedback path delay is that, sadly, when we need the QoS information the most – that is when the network conditions are highly adverse – it is exactly when they are usually received late, errored or lost altogether." [14]

The solution is to modify the existing MPEG-4 video compression technique by extending it with 'Quality of Service' (QoS) transport control protocol software. The features of this idea are that the transport control software is responsible for controlling the video compression to dynamically adapt to the network conditions. It should initially decide upon the network parameters by testing the data transmission rate of the Bluetooth link being used. This would then determine the maximum sending rate and hence the video compression bit-rate can be set so that it matches the network bandwidth for maximum efficiency and quality of streamed video. In the statement below we can see that the MPEG-4 video compression scheme does not implicitly define a QoS system. For video transmission over Bluetooth this would need to be added to the codec externally using an intelligent bit-rate control.

"MPEG-4 offers transparent information, which can be interpreted and translated into the appropriate native signalling messages of each network with the help of relevant standards bodies. The foregoing, however, excludes Quality of Service considerations, for which MPEG-4 provides a generic QoS descriptor for different MPEG-4 media. The exact translations from the QoS parameters set for each media to the network QoS are beyond the scope of MPEG-4 and are left to network providers. Signalling of the MPEG-4 media QoS descriptors end-to-end enables transport optimization in heterogeneous networks." [15]

The proposed solution may have to deal with instances when there is total signal lost between the two devices. In this case the system should fail gracefully, meaning that the receiver would stop playing video and wait for the connection to be reset. Once a connection has been established again, the encoder can send a full I-frame to minimise any errors such as artefacts.

When partial data loss occurs, the receiver can minimise the impact of this on the displayed video by using techniques such as image smoothing. This involves 'guessing' parts of an image that have been lost by using the surrounding blocks. With 8, 4 or 2 neighbouring blocks received (see figure 5 below), the missing block can be recovered using spatial and temporal information from the other blocks. [16]

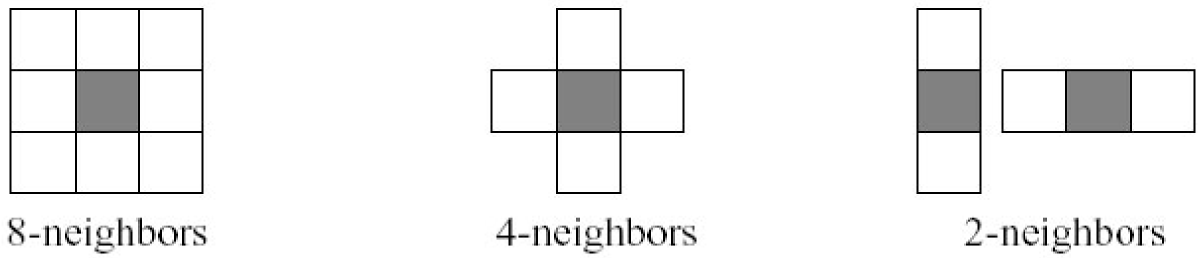

Fig 5.Recovering lost blocks using neighbouring blocks, white blocks are correctly received blocks, dark blocks are lost

This scheme is very easily implemented in the video decoder and is well suited for real-time video decoding applications. However, a drawback of the scheme is that it can lead to blocking artefacts resulting in a bad picture, but this would be preferable to having areas of blank pixel blocks. It is important for this error concealment scheme to work, that the video image blocks are randomly scattered so lost blocks are not localised. With isolated blocks having the highest number of correct neighbouring blocks, they can be recovered with the highest degree of accuracy.

Fig 6. Degraded image (left), error concealed image (right)

It is also important to remember the effects of error concealment in terms of time delay, as these techniques may require high levels of computational power which must be offset against providing real-time video with minimal delay. To improve the success of the error concealment scheme, the encoded video can be ‘block-shuffled’ into a random sequence. The idea here is that when the video is being transmitted the blocks are not sent in order so that any losses occurring will contain blocks that are scattered throughout the image. The receiver then has a higher chance of correctly guessing these missing blocks as they will have many surrounding blocks and localised losses are minimised. The quantified benefits of this method are given below.

"We introduce a new block shuffling scheme to isolate erroneous blocks caused by packet losses. And we apply data hiding to add additional protection for motion vectors. The incorporation of this scheme adds little complexity to the standard encoder. Experimental results suggest that our approach can achieve a reasonable quality for packet loss up to 30% over a wide range of video materials.” [11]

Conclusion

The current challenges with providing multimedia over wireless networks such as Bluetooth include limited bandwidth and much higher error rates than with existing reliable wire-based networks. Research is currently exploring the best ways of overcoming both these factors and possible, limited solutions are available. The problems faced with wireless Bluetooth multimedia are outlined below.

“Narrow bandwidth, limited computational capacity, and reliability of the transmission media are limitations that currently hamper wide-spread use of multimedia here [Bluetooth devices]. *Providing improved error resilience, improved coding efficiency, and flexibility in assigning computational resources would bring mobile multimedia applications closer to reality.”* [17]

The proposed method of reducing video and audio to meet the requirements of the Bluetooth data bandwidth is to use compression. MPEG-4 is the most appropriate compression method for use in this situation as it provides very low bit-rates and high compression. This means that is ideal for low bandwidth networks like Bluetooth which has a limited, 721 Kbit/s maximum, data rate. The MPEG-4 compression technique is an industry standard so compatibility is widespread where software and hardware encoders and decoders already exist. These include some open source and free software versions currently in development. [18]

To combat the unreliable nature of wireless networks such as Bluetooth, an intelligent QoS transport control must be employed. This would dynamically adapt to the conditions of a connection between two Bluetooth devices, using the information to make necessary changes to the video encoder and transmission of data. The aim is to minimise the effects of interference and data packet loss to the end user watching a video, whilst maximising the quality of this video. The video decoder can also provide extra functionality to smooth out any packet losses by providing error concealment algorithms to ‘cover up’ gaps in a video frame. With these techniques in place, high quality video transmission over Bluetooth wireless technology would be possible. This could be used in a variety of applications and lead to an exciting new frontier in wireless communication.

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