Video Streaming over Bluetooth: A Survey

Wang Xiaohang (XXXXXXXX)
Institute for Infocomm Research (I2R) / School of Computing, NUS
xwang@i2r.a-star.edu.sg

ABSTRACT

In recent years, wireless ad hoc networks have been a growing area of research. The advent of Bluetooth wireless technology makes it possible to transmit real-time video/audio in mobile and pervasive environments. In comparison with the other wireless standard such as 802.11x and IrDA, Bluetooth is more cost-efficient and power-efficient, making it ideal for small, light mobile devices. However, current Bluetooth network is not suitable for traditional media encoding and real-time transmission due to limited bandwidth, high degree of error rates, and the time-varying nature of the radio link. Therefore, media streaming over Bluetooth poses many challenges. To address these challenges, recent research has been conducted. In this paper, we review recent studies in the field of media streaming over Bluetooth. Specially, we cover three major areas - intermediate protocols, QoS control and media compression. For each area, we address the particular issues and review major approaches to adopt existing media streaming techniques for Bluetooth environments.

Keywords

Bluetooth, Media Streaming, Video, Audio, QoS Control, Media Compression, intermediate protocol

1. INTRODUCTION

1.1 Bluetooth Background

Bluetooth is a wireless technology to connect mobile and pervasive devices over the ISM (Industrial Scientific Medical) band. It offers capability of medium speed transmission with range up to 100 meters, thus enabling the transmission of continuous media in an ad hoc environment.

Bluetooth supports three kinds of connection scheme for forming *ad hoc* networks: point-to-point, piconet and scatternet. Point-to-point connection enables two devices directly communicate with on another. A point-to-multipoint topology is provided by a piconet, in which only one device acts as the master and the other as a slave. A more complex network scheme is referred to as a scatternet. In a scatternet, slaves in one piconet can participate in another piconet as either a master or slave through time division multiplexing.

Unlike many other wireless standards, the Bluetooth wireless specification includes physical layer, link layer and application layer definitions which supports data, voice, and content-centric applications. Bluetooth link-layer supports two types of link

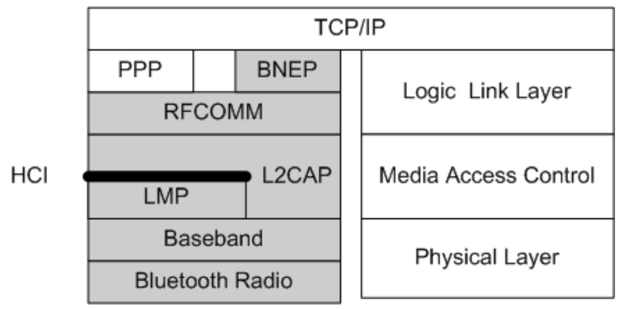

Figure 1. The Protocol Stack of Bluetooth

modes between master and slave devices. They are known as Synchronous Connection Oriented (SCO) link and Asynchronous Connection-Less (ACL) link. SCO is symmetrical point-to-point circuit switched connection with up to 64Kbps bandwidth, which is typically used in QoS-guaranteed bi-directional streaming like voice transmission. ACL links can support point-to-multipoint communication with up to 732Kbps downlink bandwidth and 128Kbps uplink bandwidth. ACL links can afford enough bandwidth for streaming media, and support broadcast styled connection.

Bluetooth facilitates data and voice transmission with a series of protocols [12]. As shown in figure1, baseband is the physical layer where Bluetooth performs all low-level data processing including basic FEC and ARQ error correction, packets handing, data whitening, hop selection and security. Link Manager Protocol (LMP) handles link control, power-sensitive states changing, and data encryption. Logical Link and Control Adaptation Protocol (L2CAP) provides both connection-oriented and connectionless data services to upper layer protocols with segmentation and reassembly operation. L2CAP only supports ACL links with packet size up to 64Kbytes. L2CAP and LMP serve as a Media Access Control (MAC) layer. Host Controller Interface (HCI) provides a uniform interface method to access hardware capabilities. It is responsible for transmitting data between L2CAP and baseband through a physical bus (e.g., USB, RS232 and PCI) using LMP. Lying on the logic link layer, RFCOMM emulates a serial port and allow transfer of data and voice from L2CAP. Bluetooth specification also defines how to access TCP/IP network using IETF Point-to-Point Protocol (PPP) or Bluetooth Network Encapsulation Protocol (BNEP). With TCP/IP bridging to Bluetooth, media streaming tasks can be made simpler by transferring media streams over Bluetooth links at the cost of additional overhead added by upper layers.

Bluetooth specifications can be classified into a core specification and a number of profile definitions. Bluetooth core specification contains the Bluetooth radio specification as well as the baseband, link manager, L2CAP, service discovery, RFCOMM, IrDA and other core functions. Bluetooth profile specifications provide details of the applications such as generic access, service discovery, cordless telephony, intercom, serial port, headset, dial-up networking, local area networking, etc.

1.2 Architecture for Video Streaming over Bluetooth

Traditional video streaming over wired/wireless networks typically has band-width, delay and loss requirements due to its real-time nature. More over, there are many potential reasons including time-varying features, out-of-range devices, and interference with other devices or external sources that make Bluetooth links more challenging for video streaming.

To address these challenges for video streaming over Bluetooth links, recent research has been conducted. To present various issues and give a clear picture of the field of video streaming over Bluetooth, we discuss three major areas, namely video compression, QoS control and intermediate protocols. Each of the areas is one of the basic components in building a complete architecture for streaming video over Bluetooth. The relations among them can be illustrated in Fig.2.

Figure 2 shows functional components for video streaming over Bluetooth links. Moreover, the layer/layers over which a component works is also indicated. The aim of video compression is to remove redundant information form a digitized video sequence. Raw data must be compressed before transmission to achieve efficiency. This is critical for wireless video streaming since the bandwidth of wireless links is limited to 732Kbps. Upon the client's request, the media sever retrieves compressed video and the QoS control modules adapts the media bit-streams, or adjusts transmission parameters of intermediate layer based on the current link status and QoS requirements. After the adaptation, compressed video stream are partitioned into packets of the chosen intermediate layer (e.g., L2CAP, HCI, IP), where packets are packetized and segmented. It then sends the segmented packets to Bluetooth module for transmission. On the receiving side, the Bluetooth module receives media packets from air, reassembles them in the intermediate protocols, and sends them to decoder for decompression.

As shown in figure 2, QoS control can be further categorized into congestion control and error control. Congestion control in Bluetooth is employed to prevent packet loss and reduce delay by regulating transmission rate or reserving bandwidth according to changing link status and QoS requirements. Error control, on the other hand, is to improve video quality in the presence of packet loss.

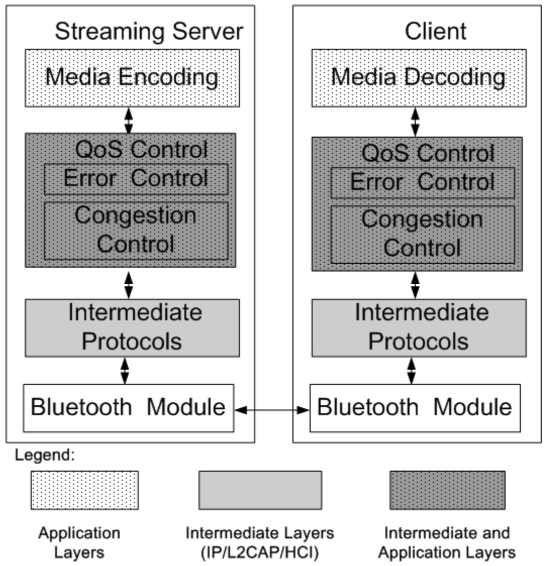

Figure 2. Architecture for streaming over Bluetooth

The remainder of this paper is devoted to the exposition of the above mentioned three areas. Section 2 overviews and compares various intermediate protocols of Bluetooth for video streaming. Section 3 presents QoS control mechanisms including error control and congestion control for Bluetooth based video streaming. Section 4 discusses video compression techniques that are designed for low-bandwidth video streaming over wireless links. Section 5 summarizes this paper.

2. Intermediate Protocols

Bluetooth protocols deal with physical and link layer operations, while also provide flexible interfaces for interacting with upper layers. Among multiple layers in the Bluetooth protocol stack, it is very important to choose a proper intermediate protocol for packetizing and segmenting media streams. M. H. Chia and M. Salim Beg [1] proposed and compared HCI, L2CAP and IP as alternative intermediate protocols for video streaming over Bluetooth.

The proposed implementations are named as MPEG-4 over Bluetooth (MPEG4BT) via HCI, MPEG4BT via L2CAP, and MPEG4BT via IP over Bluetooth. A qualitative comparison of the three intermediate layers is made based on the size of the overheads, the efficiency of segmentation and reassembly processes, and hardware compatibility.

Implementation issues of streaming video via different layers over Bluetooth are also discussed in [2, 4]. It is suggested that video streaming via IP and L2CAP can be achieved using three Bluetooth specifications – Local Area Network Access Point Profile (LAP [13]), Bluetooth Network Encapsulation Specification (BNEP [14]) and Audio/Video Distribution Transport Protocol (AVDTP [15]).

2.1 Streaming via HCI

For streaming via HCI, video bit-streams are directly packetized into HCI packets to send down to baseband for transmitting over air. This approach can maximize the bandwidth usage and minimize overhead by exposing the internal operation to lower layer. In HCI layer, the size of packets depends on the buffer size. Since HCI does not have segmentation and reassembly (*SAR*) function, application-layer software need to perform SAR based on HCI buffer size. This loads the host system resources and therefore impacts the overall performance, as MPEG-4 compression needs very high processing power. Another disadvantage is that using HCI without L2CAP is not allowed in current Bluetooth protocol, which asks for the change of hardware and software specification.

2.2 Streaming via L2CAP

Streaming via L2CAP hides the peculiarities of the Bluetooth low-layers, thus making it possible for existing applications to run over Bluetooth links without too much modification. L2CAP can facilitate the SAR of larger-size, higher-layer packets to and from the smaller baseband packets. Nevertheless, this method produces more overheads compared to HCI because of extra bits needed for L2CAP packet encapsulation.

Bluetooth streaming via L2CAP is defined by three draft specifications covering the protocols and profiles: Audio/Video Distribution Transport Protocol (AVDTP), Audio Video Control Transport Protocol (AVCTP) and Generic Audio/Video Distribution Profile (GAVDP). Following these A/V specifications, a sender could stream Real Time Protocol (RTP) packets to a receiver across L2CAP channels at high quality independent from video codec's.

In AVDTP specification, it is suggested that L2CAP channels are best suited for the support of A/V stream data distribution links, because L2CAP can be flexibly configured to enable bandwidth to be shared between multiple A/V content streams. AVDTP applies point-to-point signalling over a pseudo-isochronous, connection-oriented L2CAP ACL channel. Both A/V streams and signalling messages are transported via the same physical L2CAP channels.

AVDTP Signalling provides stream discovery, configuration, establishment, and transfer control. When A/V applications transport audio and/or video streams over Bluetooth links, AVDTP performs A/V parameter negotiation. Based on the result of this negotiation, A/V applications transport audio and/or video content.

2.3 Streaming via IP

Streaming via IP over Bluetooth relies on the bridging of TCP/IP and Bluetooth. Its main advantage is that IP-based video streaming mechanisms such as RTP can be transparently used without modification. The method is actually a duplication of the functionality provided directly by IP-based video streaming. However, this convenience is achieved at the cost of overhead added by upper layers, which may penalize performance due to the limited bandwidth provided by Bluetooth.

Bluetooth streaming via IP can be achieved by using LAP or BNEP:

LAP defines general procedures to set up a Point-to-Point Protocol (PPP) link over RFCOMM and thus allow IP packets to flow across the link. The profile specifies two components on being a client accessing the services of a network by the means of using a gateway known as a Bluetooth access point. This is normally hard wired to the network.

BNEP describes the process to send TCP or UDP over L2CAP. Following BNEP, the packets traverse each TCP/IP stack layer and in turn a header is added onto the original packet, then it is channeled through the Ethernet Frame layer and finally through L2CAP. The application on the receiving side processes the packet and converts it back into video streams.

Compared to streaming via L2CAP, LAP and BNEP enables streaming via IP over Bluetooth by processing upper layer packet headers across L2CAP links. As the video stream is packetized in IP layer, it adds an additional encapsulation layer between the L2CAP encapsulation layer, and the encapsulation provided by IP, such that there are at least three encapsulation layers for an IP Bluetooth solution: L2CAP, BNEP/LAP, and IP.

2.4 Discussion on Intermediate Protocols

Table 1 gives a clear comparison of video streaming over different intermediate protocols. Taking various factors into consideration, L2CAP and IP appear to be feasible intermediate layers for streaming over Bluetooth. However, there always exists a trade off between efficiency in term of encapsulation overhead and implementation complexity.

Table 1. Comparison of streaming via different protocols

	HCI	L2CAP	IP
Logical OSI Layer	Link	Link	Network
Implementation Complexity	High	Medium	Low
Modified Part	Hardware	Software	Software
Segmentation and Reassembly Support	No	Yes	Yes
Point-to-Multipoint Support	No	Yes	Yes
BT Profile	N.A.	AVDTP	LAP or BNEP
Encapsulation Overhead [1]	RTP	L2CAP+ AVDTP+ RTP	L2CAP+ LAP /BNEP+IP+UDP+ RTP

[1] On the assumption that media streaming is based on RTP

Current Bluetooth profiles and specifications only define generic functions and have not been finalized. It is still not clear as to how complete A/V transport solutions can be realized and how existing streaming mechanisms can be fitted into Bluetooth networks. This provides a good opportunity for research into this new area.

3. QoS Control

The goal of QoS control is to avoid congestion and maximize video quality in the presence of packet loss.

This section discusses how various QoS mechanisms are adopted for Bluetooth environment [3, 6, 8, 9, 10, 15].

3.1 Error Control

There are many potential reasons including out-of-range devices, interference with other devices or external sources that make Bluetooth links have a high degree of error rates. Recent work [3, 9, 10, 15] on this area study the adoption of error control mechanisms including link layer and upper layer FEC, retransmission, error-resilient encoding and error concealment to facilitate error control for streaming over Bluetooth links.

3.1.1 Link Layer FEC and ARQ

Bluetooth ACL link provides three built-in baseband error correction techniques: 1/3 rate FEC, 2/3 rate FEC, and ARQ [12]. The 1/3 rate FEC scheme is adopted in the header of L2CAP packets; this scheme simply repeats the same bit three times. The other two are applied to the payload.

The principle of FEC is to add redundant information to original message so that it can be reconstructed in the presence of packet loss. The FEC methods are designed to reduce the chances of getting corrupted information and inturn reduce the number of retransmissions. It is widely known that FEC is suited for real-time communications. But varying channel conditions limit its effective use, since a worst-case design may lead to a large amount of overhead, which makes it generally used in relatively error-free environments.

ARQ is a kind of basic delay-constrained retransmission mechanism that is usually dismissed as a method to recover lost packets in real-time video since a retransmitted packet may miss its play-out time. ARQ incurs less overhead than FEC, but is correspondingly less effective, lacking any ability to correct errors. The ARQ scheme requires that header error and CRC are correct, when they are, ACK is sent. If the transmitter does not receive an ACK it resends the data after a predefined time.

Bluetooth built-in error control mechanisms are designed for general data transmission. The methods discussed in following sections adapt them for real-time streaming over Bluetooth links.

3.1.2 Upper Layer FEC

The link layer FEC is intended to limit the number of retransmissions needed in the presence of packet loss. However, this feature does not help much for significant burst. In addition, the baseband FEC service is not selectable for each logical channel separately.

In the specification of AVDTP [15], it is proposed that an upper-layer FEC scheme that protects video packets directly in the transport layer. The benefit of the upper-layer recovery is to provide the means for applications to differentiate the protection according to the video packet types or contents. For instance, an application can decide to protect either video packets or audio packets depending on their respective error-resilience capability or to limit the protection to some vulnerable parts of the stream.

AVDTP improves the Bluetooth link layer FEC scheme by separating the transmission of media packets and recovery packets into different logical channels (i.e., media channel and signaling channel). The AVDTP recovery service is based on the RTP payload format for generic FEC, which provides a specification of the packet format to be adopted for generation and encapsulation of the FEC recovery packets. It also mandates the procedures to be used for media packet reconstruction at the receiving side.

In order to provide the means to differentiate the protection according to the packet types or contents, AVDTP recovery module use two channels for independently transmitting media packets and recovery packets. This recovery service operates independently of the other AVDTP services in a dedicated transport session. A brief recovery process is described as follow:

At the sender side, the service is active on application demand through a specific interface. Recovery packets are generated from the set of media packets to be protected. Then the generated recovery packets are automatically filed onto the associated recovery channel without intervention of media transmission. At the receiver side the service is directly triggered each time a missing media packet is detected in a protected transport session: The recovery service attempts to restore the missing packet using one or several subsequent recovery packets, which have the missing media packet in scope.

We believe that the separation of media and signaling channels provides a potential support for the differentiation of protection based on the media type and content, which could be further extended to exploit the semantic of packets to perform "*priority-related FEC*".

3.1.3 Upper Layer Retransmission

H. Okura et al [6] has studied the effect of link layer ARQ on the delay jitters of ACL link. It is suggested that delay of ACL link is attributed to two major reasons. One is the baseband contention caused by multiple slaves competing time slot to communicate with a master. The other reason is bandwidth usage due to ARQ retransmission. The performance study suggests that native ARQ is a performance bottleneck in video transferring over Bluetooth links so that it is not suitable for video streaming QoS control in this field.

Rohit Kapoor et al [3] proposed cross-layer optimization approach to improve packet retransmission. The key idea is inspired by the famous "selective retransmission". The novelty of this approach is to make link layer (L2CAP and HCI) aware of application layer header information. The basic principle behind the scheme is the following: "If a given bandwidth reserved for a video flow allows each frame to be retransmitted a certain number of times on the average, and then the quality of video can be increased by increasing the number of times retransmitted and decreasing the number of times the dependent P/B frames are retransmitted".

Having knowledge of the semantic priority of different types of MPEG frames, the selective retransmission scheme trades off the increase in reliable reception of I frames with a decrease of P/B frames. The simulation results showed an improvement in video quality using this selective retransmission scheme compared to standard link-layer ARQ scheme of Bluetooth.

Moreover, this paper also discussed implementation issues of cross-layer optimization. It is suggested that selective retransmission of L2CAP packets can be implemented using '*Flush*' APIs defined in Bluetooth L2CAP specification. Applications can use the specified command 'Write Flush Timeout' to set the buffer flush timeout for each L2CAP packets, thus affecting the retransmission of media packets of different type.

3.1.4 Error Concealment

Error concealment [9] is performed on the receiver side to conceal the lost data and make the video less displeasing to human. There are two basic approaches for error concealment, spatial and temporal interpolation. In spatial interpolation, missing pixel values are reconstructed using neighboring spatial information. In temporal interpolation, the lost data is reconstructed from data in the previous frames.

S. Miaou, et al proved using performance study that even the simplest temporal error concealment technique can improve the quality degradation of H.263 video under lossy Bluetooth links.

3.1.5 Error-resilient Encoding

The objective of error-resilient encoding is to enhance robustness of compressed video to packet loss. The standardized error-resilient encoding schemes include re-synchronization marking, data partitioning, and data recovery.

M. Fahim Tariq et al. [10] proposed an error resilient implementation of the matching pursuits algorithm for H.263 video encoding over Bluetooth. The experiment shows that this strategy is superior in term of PSNR to built-in ARQ error correction scheme in the presence of baseband channel error.

3.2 Congestion Control

Loss and delay have devastating effect on video presentation quality and they are often caused by network congestion. Thus, congestion control mechanisms are important to help reducing packet loss and delay. This would dynamically adapt to the conditions of a connection between devices, using feedback to make necessary changes to transmission rate.

A few works in this area have discussed various congestion control schemes for video streaming over Bluetooth [4, 8, and 11].

3.2.1 Rate Control

Rate control is a technique used to determine the sending rate of video streaming traffic on the estimated available bandwidth. Existing rate control schemes can be classified into source-based and receiver-based control. Under the source-based rate control, the sender is responsible for adapting the video transmission rate. On the contrary, under receiver-based rate control, the receiver regulate rate of media streams by adding/dropping channels while the sender does not participate.

Recent research has been conducted to provide adaptive sender-based rate control for streaming over Bluetooth piconets [11] and scatternets [8]. In the streaming experiment over Bluetooth picnets [11], the adaptation mechanism is based on an end-to-end periodic feedback that contains the number of packets received during the feedback interval. This feedback is used by streaming server to compute the RTP loss rates. Then media transmission rate is regulated using a min/max loss threshold. Below the minimum packet loss rate (5%) the server attempts to additively increase its rate. When loss rate is above the maximum loss threshold (15%) the server reduces the sending rate, choosing an appropriate rate among 48, 64, 80, 128 and 256Kbps that are supported by H.263 codec. The same experiment on Bluetooth and 802.11shows that adaptive video streaming is better with Bluetooth than 802.11, in part because the polling schedule of Bluetooth seems to offer a more stable service.

This adaptive rate control scheme is further extended to Bluetooth scatternet environments, which is actually the interconnection of piconets [8]. It is suggested that in Bluetooth scatternets, gateways effectively limit the capacity at a fraction of link layer data rate, while closed loop end-to-end adaptation can be effective in controlling congestion and improving user perceived OoS. This is attributed to the very controlled master centric polling MAC layer (i.e., L2CAP) in combination with the time invariant inter-piconet scheduling mechanism that Bluetooth employs.

3.2.2 Rate Reservation

Resource reservation has been an extensively studied area for supporting timing critical applications such as VoIP and continuous media applications. In Bluetooth environment, when more media streams compete for the limited bandwidth at same time, resource reservation, especially rate reservation could be very effective. Corian Scheiter et al. [4] proposed a rate reservation scheme to address this problem.

HCI is responsible for transmitting data between L2CAP and baseband, therefore rate reservation over Bluetooth can be implemented using HCI interfaces. Applications can request a specific transmission rate by an additional resource manager that controls the access to the network. The master can assign data rates to different streaming sessions by changing the poll interval of the connection with slaves. Because of the mobility and the dynamic behavior of Bluetooth devices, the resource manager continuously monitors the actual state of the network (reservations, traffic lode, bit error rate etc). In case of too poor link quality, the resource manager informs the application layer about the changes. The application layer could then adjust the video codec settings or decrease the data rate of other streaming sessions with lower priority.

3.3 Discussion on QoS Control

This section has reviewed various QoS control schemes including error control and congestion control that are proposed to improve the quality of video streaming over Bluetooth.

Traditional QoS control over Internet is mainly implemented in application-layer or transport-layer, and multiple protocol layers often operate without knowledge of each other. On the other hand, Bluetooth mainly provides physical- and link-layer support. Efficient media streaming over Bluetooth requires higher layers' operation be replaced with low layer processes, as the fast response and low overhead of link layer make it an ideal place for QoS control. Therefore, the link layer of Bluetooth (i.e., L2CAP/HCI) needs to be aware of higher layer information to make adaptation.

Table 2 shows different QoS control schemes and corresponding protocol layering. Among these control schemes, Upper-Layer FEC, Upper-Layer Retransmission and Rate Reservation require the interaction of link layer (L2CAP/HCI) and application layer, thus they can be categorized into cross-layer approaches.

Table2. QoS Control Schemes vs. Protocol Layering

	Link-Layer		Application-Layer	Cross-Layer Interaction
	HCI	L2CAP		
Link-Layer FEC		v		
Link-Layer ARQ		v		
Upper-Layer FEC		v	v	v
Upper-Layer Retransmission	v	v	v	v
Error Concealment			v	
Error-Resilient Encoding			v	
Rate Control			v	
Rate Reservation	v		v	v

The idea of the cross-layer interaction has proposed in the context of wireless networks [5]. We believe that such techniques are very useful for QoS control over Bluetooth links. Currently, each network layer (i.e., physical layer, media access control, network, transport, and application layers) provides a separate solution to these challenges by providing its own optimized adaptation and protection mechanisms. However, this layered strategy does not always result in an optimal overall performance. Moreover, certain protection strategies can be implemented simultaneously in several layers, and the optimal choices from applications need to be identified.

4. Video Compression

The aim of video compression is to remove redundant information from a digitized video sequence. It is critical to choose an appropriate compression method for use in video streaming over Bluetooth, as it provides time-varying wireless link with limited bandwidth up to 732Kbps.

This section briefly describes video compression techniques including MPEG-4 and H.263 that are used by current researches of this area.

4.1 MPEG-4

A large portion of works [1, 3, 4, and 8] reviewed in previous sections employ MPEG-4 as video codec for streaming over Bluetooth.

MPEG-4 is one of the newest video compression techniques and allows much lower compression ratios than the previous MPEG-2. MPEG-4 is ideally suited to low bandwidth applications, exactly matching the requirements for video over a wireless Bluetooth network.

MPEG-4 uses motion vectors between frames to encode temporal redundancy and the discrete cosine transform (DCT) to encode spatial redundancy. MPEG-4 provides three modes for encoding an input, 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

For frames other than I frames, the amount of information to be coded reduces to differences between frames. This differential coding means that I frames are more important since all future frames till the next I frame are coded based on it. Therefore, extensive research on exploiting the information on the type of video frames has been proposed. Among these researches, *upper layer retransmission* [3] mentioned in 3.1.3 is a kind of selective retransmission based on semantic importance of MPEG-4 frames in the context of streaming over Bluetooth links.

4.2 H.263

Several works [7, 9, and 11] reviewed in previous section employ H.263 as video codec for streaming over Bluetooth.

H.263 is a video compression algorithm and protocol which is standardized by ITU. It was designed for low bit-rate communication. The video source coding algorithm of H.263 is based on Recommendation H.261 and is a hybrid of inter-picture prediction to utilize temporal redundancy and transform coding of the remaining signal to reduce spatial redundancy, however with some changes to improve performance and error recovery.

H.263 lets users scale bandwidth usage and can achieve full-motion video (30 frames per second) at speeds as low as 128Kbps. H.263 was also developed to low-quality stream video at bandwidths as low as 20 to 64Kbps. Compared to MPEG-4, H.263 does not support some of the features such as compression efficiency and channel error robustness. However, it is widely accepted that it performs well for the target application at bi-rate between 20 and 64 Kbps. Therefore it is widely used in wireless networks with limited bandwidth.

4.3 Discussion on Video Compression

Video compression is a massive research area, and it is one of the key issues for streaming over Bluetooth wireless links. However, there are not many articles on this field. MPEG-4 and H.263 belong to non-scalable video codec which generate fixed compressed bit-stream. In contrast, we can exploit scalable encoding mechanisms to provide more flexibility in meeting different demands of streaming. Such adaptive compression methods can adapt to changing bandwidth and QoS requirement to provide a better service quality.

5. Conclusion

Bluetooth is an exciting technology for mobile devices and serves the purpose of streaming video in *ad hoc* network environments. However, there are not many researches conducted on the field of streaming video over Bluetooth. This provides a good opportunity for research into this new area.

Bluetooth specifications and profiles provide physical layer, link layer, and upper layers supports. Among multiple layers, it is very important to choose a proper intermediate protocol for packetizing and segmenting media streams. Taking the tradeoff between encapsulation efficiency and implementation complexity into account, L2CAP and IP are feasible intermediate protocols.

Current QoS control mechanisms typically works on a single network layer, and provide a separate solution by providing its own optimized adaptation mechanisms. A promising next-step in field of OoS control over Bluetooth wireless links could be “cross-layer interaction” techniques. By integrating different adaptive QoS mechanisms available in the different layers for transmission of video (namely error control, congestion control, bandwidth-adaptive compression, and adaptive packetization etc.), we can provide an optimal cross-layer QoS strategy for enhancing the robustness and efficiency of video transmission over Bluetooth links.

Video compression is critical for video streaming over Bluetooth due to the time-varying link, limited bandwidth, and resource-constraint devices. We could exploit scalable encoding mechanisms to provide more flexibility in meeting different QoS requirement and changing bandwidth.

References

[1] Chong Hooi Chia and M. Salim Beg, "MPEG-4 video transmission over Bluetooth links", Proc. IEEE International Conf. on Personal Wireless Communications, New Delhi, 15-18 Dec 2002.

[2] Amrit Prit Paul Singh Bilan, “Streaming Audio Over Bluetooth ACL Links”, Proc. 2003 International Conference on Information Technology: Computers and Communications (ITCC’03), 2003.

[3] Rohit Kapoor, Matteo Cesana, Mario Gerla , “ Link Layer Support for Streaming MPEG Video over Wireless Links”, 2003 International Conference on Computer Communications and Networks (ICCCN 2003), 2003.

[4] Corina Scheiter, Rainer Steffen, et al, “A System for QoS-Enabled MPED-4 Video Transmission over Bluetooth for Mobile Applications”, 2003 International Conference on Multimedia and Expo (ICME '03), 2003.

[5] Bhaskaran Raman, Pravin Bhagwat, and Srinivasan Seshan, “ Arguments for Cross-layer Optimizations in Bluetooth Scatternets”, Proc. Symposium on Applications and the Internet, 2001.

[6] Hirotsugu Okura, Masami Kato, and Shuji Tasaka, “A Media Synchronization Experiment on Continuous Media Transmission in Bluetooth LAN Access”, 12th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 2001

[7] Hirotsugu Okura, Masami Kato, and Shuji Tasaka, “The Effect of Segmentation Mismatch on Quality of Continuous Media Transmission by Bluetooth”, .The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 2002.

[8] Manthos Kazantzidis, Andrea Zanella, Mario Gerla, “End-to-end Adaptive Multimedia over Bluetooth Scatternets”, Proceesings of Eurel AICA European Wireless Conference, 2002.

[9] Shauo-Gang Miaou, Chia-Yuan Huang, et al, “Quality Degradation and Improvement of H.263 Video Transmitted in Bluetooth Packets under the Interference of Wireless LAN”, IEEE GlobeCom 2002, Taipei, China, 2002.

[10] Tariq M.F., Czerepinski P., Nix A., Bull D., Canagarajah N., “Robust and scalable matching pursuits video transmission using the Bluetooth air interface standard”, International Conference on Consumer Electronics, 2000

[11] Rohit Kapoor, Manthos Kazantzidis, Mario Gerla and Per Johansson, "Multimedia Support over Bluetooth Piconets", Wireless Mobile Internet, 2001.

[12] Bluetooth Special Interest Group, "Specification of the Bluetooth System", version 1.1.

[13] Bluetooth Special Interest Group, "Specification of the Bluetooth System: Part K:9 LAN Access Profile, version 1.1, 2002"

[14] Bluetooth Special Interest Group, "Bluetooth Network Encapsulation Protocol (BNEP) Specification" version 0.95, Draft, 2001, Bluetooth PAN Working Group

[15] Bluetooth Special Interest Group, "Audio/Video Distribution Transport Protocol Specification" version 1.00a, Draft, 2002, Bluetooth Audio Video Working Group

[16] IETF RFC2733 – An RTP Payload Format for Generic Forward Error Correction