Bluetooth WHITE PAPER	DATE Aug 25th 99	N.B.	DOCUMENT NO 1.C.120/1.0

RESPONSIBLE	E-MAIL ADDRESS	STATUS
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Bluetooth Protocol Architecture

Version 1.0

This white paper describes the protocol architecture developed by the Bluetooth Special Interest Group (SIG). Various usage models are presented and complemented with a description of the protocols relevant to their implementation.

Special Interest Group (SIG)

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1 Introduction

The Bluetooth Special Interest Group (SIG) has developed the Bluetooth Specification Version 1.0 Draft Foundation (thereafter to be referred to as the ”Specification”), that allows for developing interactive services and applications over interoperable radio modules and data communication protocols. The objective of this paper is to provide an overview of the protocols in the Specification, their capabilities and the relation to each other (referred to as the “Bluetooth protocol architecture”). Moreover, a number of usage models identified by the Bluetooth SIG will be presented and it will be shown how (and which of) these protocols are stacked to support these usage models.

1.1 Bluetooth Protocol Stack

The ultimate objective of the Specification is to allow applications written in a manner that is conformant to the Specification to interoperate with each other. To achieve this interoperability, matching applications (e.g., corresponding client and server application) in remote devices must run over identical protocol stacks. The following protocol list is an example of a (top-to-bottom) protocol stack supporting a business card exchange application: vCard → OBEX → RFCOMM → L2CAP → Baseband. This protocol stack contains both an internal object representation convention, vCard, and “over-the-air” transport protocols, the rest of the stack.

Different applications may run over different protocol stacks. Nevertheless, each one of these different protocol stacks use a common Bluetooth data link and physical layer, see more details on the protocol layers in the next section. Figure 1 shows the complete Bluetooth protocol stack as identified in the Specification on top of which interoperable applications supporting the Bluetooth usage models are built. Not all applications make use of all the protocols shown in Figure 1. Instead, applications run over one or more vertical slices from this protocol stack. Typically, additional vertical slices are for services supportive of the main application, like TCS Binary (Telephony Control Specification), or SDP (Service Discovery Protocol). It is worth of mentioning that Figure 1 shows the relations how the protocols are using the services of other protocols when payload data needs to be transferred over air. However, the protocols may also have some other relations between the other protocols. E.g., some protocols (L2CAP, TCS Binary) may use LMP (Link Manager Protocol) when there is need to control the link manager.

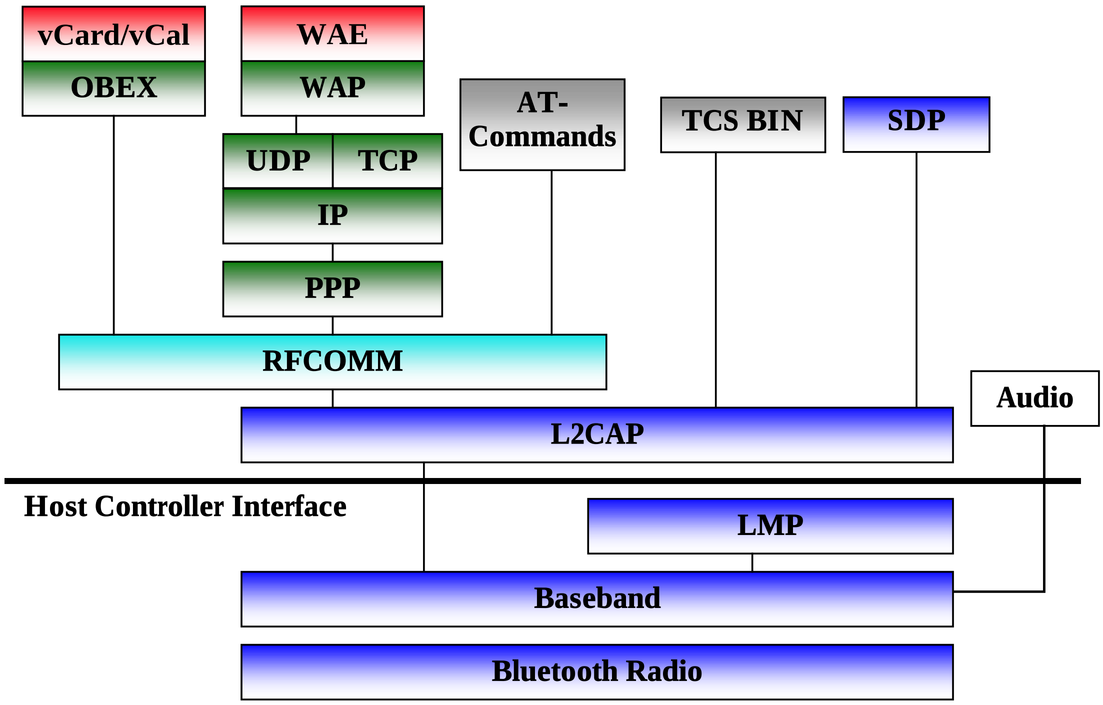

Figure 1 Bluetooth Protocol Stack

As seen in Figure 1, the complete protocol stack comprises of both Bluetooth-specific protocols like LMP and L2CAP, and non-Bluetooth-specific protocols like OBEX (Object Exchange Protocol) and UDP (User Datagram Protocol). In designing the protocols and the whole protocol stack, the main principle has been to maximize the re-use of existing protocols for different purposes at the higher layers, instead of re-inventing the wheel once again. The protocol re-use also helps to adapt existing (legacy) applications to work with the Bluetooth technology and to ensure the smooth operation and interoperability of these applications. Thus, many applications already developed by vendors can take immediate advantage of hardware and software systems, which are compliant to the Specification. The Specification is also open, which makes it possible for vendors to freely implement their own (proprietary) or commonly used application protocols on the top of the Bluetooth-specific protocols. Thus, the open Specification permits the development of a large number of new applications that take full advantage of the capabilities of the Bluetooth technology.

2 Protocols in Bluetooth Architecture

The Bluetooth protocol stack can be divided into four layers according to their purpose including the aspect whether Bluetooth SIG has been involved in specifying these protocols. The protocols belong into the layers in the following way.

Protocol layer	Protocols in the stack
Bluetooth Core Protocols	Baseband [1], LMP [2], L2CAP [3], SDP [4]
Cable Replacement Protocol	RFCOMM [5]
Telephony Control Protocols	TCS Binary [6], AT-commands [7],[8],[9]
Adopted Protocols	PPP [10], UDP/TCP/IP [10], OBEX [11], WAP [12], vCard [13] , vCal [14], IrMC[1] [15], WAE [16]

Table 1: The protocols and layers in the Bluetooth protocol stack

In addition to the above protocol layers, the Specification also defines a Host Controller Interface (HCI), which provides a command interface to the baseband controller, link manager, and access to hardware status and control registers. This interface is not discussed further in this paper, but more information can be obtained from the functional specification of Bluetooth host controller interface [17]. In Figure 1, HCI is positioned below L2CAP but this positioning is not mandatory but HCI can exist e.g., above L2CAP.

The Bluetooth Core protocols comprise exclusively Bluetooth-specific protocols developed by the Bluetooth SIG. RFCOMM and the TCS binary protocol have also be developed by the Bluetooth SIG but they are based on the ETSI TS 07.10 [18] and the ITU-T Recommendation Q.931 [19], respectively. The Bluetooth Core protocols (plus the Bluetooth radio) are required by most of Bluetooth devices, while the rest of the protocols are used only as needed.

Together, the Cable Replacement layer, the Telephony Control layer, and the Adopted protocol layer form application-oriented[2] protocols enabling applications to run over the Bluetooth Core protocols. As mentioned earlier, the Bluetooth Specification is open and additional protocols (e.g., HTTP, FTP [10], etc.) can be accommodated in an interoperable fashion on top of the Bluetooth-specific transport protocols or on top of the application-oriented protocols shown in Figure 1.

[1] Not shown above OBEX in Figure 1.
[2] “Application-oriented” here is with respect to Bluetooth transport services and should be interpreted as any protocol layer, or application that runs on top of the Bluetooth-specific transport protocols.

2.1 Bluetooth Core Protocols

2.1.1 Baseband

The Baseband and Link Control layer enables the physical RF link between Bluetooth units forming a piconet [1]. As the Bluetooth RF system is a Frequency-Hopping-Spread-Spectrum system in which packets are transmitted in defined time slots on defined frequencies, this layer uses inquiry and paging procedures to synchronize the transmission hopping frequency and clock of different Bluetooth devices.

It provides 2 different kind of physical links with their corresponding baseband packets, Synchronous Connection-Oriented (SCO) and Asynchronous Connectionless (ACL) which can be transmitted in a multiplexing manner on the same RF link. ACL packets are used for data only, while the SCO packet can contain audio only or a combination of audio and data. All audio and data packets can be provided with different levels of FEC or CRC error correction and can be encrypted.

Furthermore, the different data types, including link management and control messages, are each allocated a special channel.

2.1.1.1 Audio

Audio data can be transferred between one or more Bluetooth devices, making various usage models possible and audio data in SCO packets is routed directly to and from Baseband and it does not go through L2CAP. Audio model is relatively simple within Bluetooth; any two Bluetooth devices can send and receive audio data between each other just by opening an audio link.

2.1.2 Link Manager Protocol

The link manager protocol [2] is responsible for link set-up between Bluetooth devices. This includes security aspects like authentication and encryption by generating, exchanging and checking of link and encryption keys and the control and negotiation of baseband packet sizes.

Furthermore it controls the power modes and duty cycles of the Bluetooth radio device, and the connection states of a Bluetooth unit in a piconet.

2.1.3 Logical Link Control and Adaptation Protocol

The Bluetooth logical link control and adaptation protocol (L2CAP) [3] adapts upper layer protocols over the baseband. It can be thought to work in parallel with LMP in difference that L2CAP provides services to the upper layer when the payload data is never sent at LMP messages.

L2CAP provides connection-oriented and connectionless data services to the upper layer protocols with protocol multiplexing capability, segmentation and reassembly operation, and group abstractions. L2CAP permits higher level protocols and applications to transmit and receive L2CAP data packets up to 64 kilobytes in length.

Although the Baseband protocol provides the SCO and ACL link types, L2CAP is defined only for ACL links and no support for SCO links is specified in Bluetooth Specification 1.0.

2.1.4 Service Discovery Protocol (SDP)

Discovery services are crucial part of the Bluetooth framework. These services provide the basis for all the usage models. Using SDP, device information, services and the characteristics of the services can be queried and after that, a connection between two or more Bluetooth devices can be established. SDP is defined in the Service Discovery Protocol specification [4].

2.2 Cable Replacement Protocol

2.2.1 RFCOMM

RFCOMM is a serial line emulation protocol and is based on ETSI 07.10 specification. This “cable replacement” protocol emulates RS-232 control and data signals over Bluetooth baseband, providing both transport capabilities for upper level services (e.g. OBEX) that use serial line as transport mechanism. RFCOMM is specified in [5].

2.3 Telephony Control Protocol

2.3.1 Telephony Control – Binary

Telephony Control protocol - Binary (TCS Binary or TCS BIN) [6], a bit-oriented protocol, defines the call control signaling for the establishment of speech and data calls between Bluetooth devices. In addition, it defines mobility management procedures for handling groups of Bluetooth TCS devices. TCS Binary is specified in the Bluetooth Telephony Control protocol Specification Binary, which is based on the ITU-T Recommendation Q.931 [19], applying the symmetrical provisions as stated in Annex D of Q.931

2.3.2 Telephony Control – AT Commands

Bluetooth SIG has defined the set of AT-commands by which a mobile phone and modem can be controlled in the multiple usage models (See Chapters 3.2 and 3.6). In Bluetooth, AT-commands, which are utilized, are based on ITU-T Recommendation V.250 [20] and ETS 300 916 (GSM 07.07) [21]. In addition, the commands used for FAX services are specified by the implementation. These may be either:

- Fax Class 1.0 TIA-578-A [22] and ITU T.31 Service Class 1.0 [23]

- Fax Class 2.0 TIA-592 [24] and ITU T.32 Service Class 2.0 [25]
- Fax Service Class 2 - No industry standard

2.4 Adopted Protocols

2.4.1 PPP

In the Bluetooth technology, PPP is designed to run over RFCOMM to accomplish point-to-point connections. PPP is the IETF Point-to-Point Protocol [10] and PPP-Networking is the means of taking IP packets to/from the PPP layer and placing them onto the LAN. Usage of PPP over Bluetooth is described in [26].

2.4.2 TCP/UDP/IP

These protocol standards are defined by the Internet Engineering Task Force and used for communication across the Internet [10]. Now considered as the most widely used protocol family in the world, TCP/IP stacks have appeared on numerous devices including printers, handheld computers, and mobile handsets. Access to these protocols is operating system independent, although traditionally realized using a socket programming interface model. The implementation of these standards in Bluetooth devices allows for communication with any other device connected to the Internet: The Bluetooth device, should it be a Bluetooth cellular handset or a data access point for example is then used as a bridge to the Internet.

TCP/IP/PPP is used for the all Internet Bridge usage scenarios in Bluetooth 1.0 and for OBEX in future versions [11]. UDP/IP/PPP is also available as transport for WAP [12].

2.4.3 OBEX Protocol

IrOBEX [27] (shortly OBEX) is a session protocol developed by the Infrared Data Association (IrDA) to exchange objects in a simple and spontaneous manner. OBEX, which provides the same basic functionality as HTTP but in a much lighter fashion, uses a client-server model and is independent of the transport mechanism and transport API, provided it realizes a reliable transport base. Along with the protocol itself, the "grammar" for OBEX conversations between devices, OBEX also provides a model for representing objects and operations. In addition, the OBEX protocol defines a folder-listing object, which is used to browse the contents of folders on remote device.

In the first phase, RFCOMM is used as sole transport layer for OBEX [11]. Future implementations are likely to support also TCP/IP as a transport.

2.4.3.1 Content Formats

vCard [13] and vCalendar [14] are open specifications developed by the versit consortium and now controlled by the Internet Mail Consortium. These specifications define the format of an electronic business card and personal calendar entries and scheduling information, respectively. vCard and vCalendar do not define any transport mechanism but only the format under which data is transported. By adopting the vCard and vCalendar, the SIG will help further promote the exchange of personal information under these well-defined and supported formats. The vCard and vCalendar specifications are available from the Internet Mail Consortium and are being further developed by the Internet Engineering Task Force (IETF).

Other content formats, which are transferred by OBEX in Bluetooth, are vMessage and vNote [15]. These content formats are also open standards and are used to exchange messages and notes. They are defined in the IrMC specification, which also defines a format for the log files that are needed when synchronizing data between devices.

2.4.4 WAP

Hidden computing usage models can be implemented using the WAP features. Bluetooth as a WAP Bearer is defined in [12].

The Wireless Application Protocol (WAP) Forum is building a wireless protocol specification [16] that works across a variety of wide-area wireless network technologies. The goal is to bring Internet content and telephony services to digital cellular phones and other wireless terminals. In Figure 2, the protocol stack of the WAP framework is depicted.

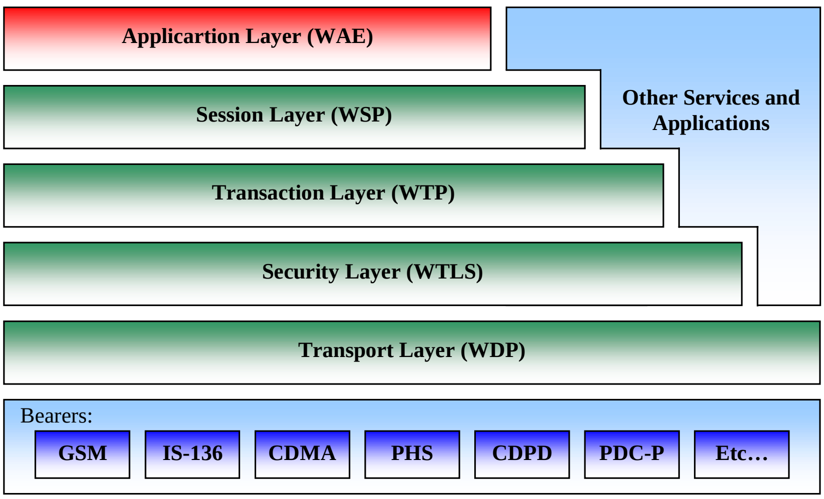

Figure 2 WAP Framework

The idea behind the choice of WAP is to reuse the upper software applications developed for the WAP Application Environment (WAE). These include WML and WTA browsers that can interact with applications on the PC. Building application gateways which mediate between WAP servers and some other application on the PC makes it possible to implement various hidden computing functionality, like remote control, data fetching from PC to handset etc. WAP servers also allow for both content push and pull between PC and handset, bringing to life concepts like information kiosks.

WAP framework also opens up the possibility of custom applications for handsets that use WML and WML Script as "universal" Software Development Kit.

2.4.4.1 Content Formats

Supported content formats for WAP over Bluetooth are WML, WMLScript, WTA event, WBMP, and vCard/vCal. These are all part of WAE. More information on WAE can be found from [16].

3 Bluetooth Usage Models and Protocols

In this chapter, the highest priority usage models identified by the SIG's marketing group are briefly introduced. Each usage model is accompanied by a Profile. Profiles define the protocols and protocol features supporting a particular usage model. Bluetooth SIG has specified the profiles for these usage models. In addition to these profiles, there are four general profiles that are widely utilized by these usage model oriented profiles. These are the generic access profile (GAP) [28], the serial port profile [29], the service discovery application profile (SDAP) [30], and the generic object exchange profile (GOEP) [31].

3.1 File Transfer

The file transfer usage model (See also the file transfer profile [32]) offers the ability to transfer data objects from one device (e.g., PC, smart-phone, or PDA) to another. Object types include, but are not limited to, .xls, .ppt, .wav, .jpg, and .doc files, entire folders or directories or streaming media formats. Also, this usage model offers a possibility to browse the contents of the folders on a remote device.

In addition, simple push and exchange operations, e.g., business card exchange are covered in the object push profile [33], with vCard specified as the format for pushed business card content.

In Figure 3, the required protocol stack presented for this usage model is presented. The figure does not show the LMP, Baseband, and Radio layers although those are used underneath (See Figure 1).

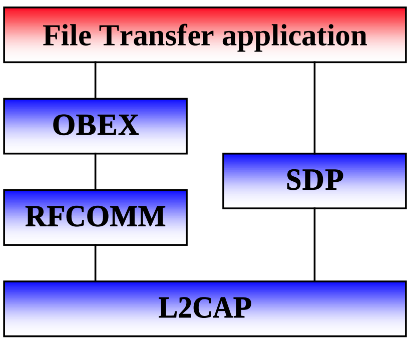

Figure 3 Protocol Stack for File Transfer Applications

3.2 Internet Bridge

In this usage model, mobile phone or cordless modem acts as modem to the PC, providing dial-up networking [8] and fax [9] capabilities without need for physical connection to the PC. The dial-up networking scenario of this usage model needs a two-piece protocol stack (in addition to the SDP branch), which is shown in Figure 4. The AT-commands are needed to control the mobile phone or modem and another stack (E.g., PPP over RFCOMM) to transfer payload data. The fax scenario has a similar protocol stack but PPP and the networking protocols above PPP are not used and the application software sends a facsimile directly over RFCOMM.

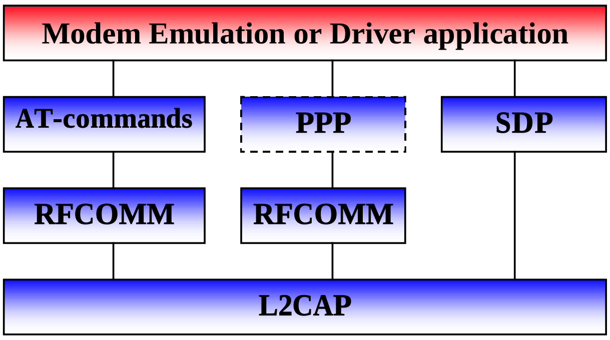

Figure 4 Dial-up Networking Protocol Stack

3.3 LAN Access

In this usage model (See also the LAN access profile [26]), multiple data terminals (DTs) use a LAN access point (LAP) as a wireless connection to a Local Area Network (LAN). Once connected, the DTs operate as if it they were connected to the LAN via dialup networking. The DT can access all of the services provided by the LAN. The protocol stack is nearly identical to the protocol stack in the Internet bridge usage model except that the AT-commands are not used. The protocol stack is represented in Figure 5.

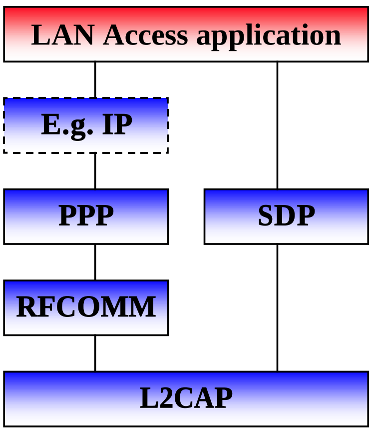

Figure 5 Protocol Stack of LAN Access (PPP) Usage Model

3.4 Synchronization

The synchronization usage model [34] provides a device-to-device (phone, PDA, computer, etc.) synchronization of the PIM (personal information management) information, typically phonebook, calendar, message, and note information. Synchronization requires business card, calendar and task information to be transferred and processed by computers, cellular phones and PDAs utilizing a common protocol and format. The protocol stack for this usage model is presented in Figure 6. In the figure, the synchronization application block represents either an IrMC client or an IrMC server software.

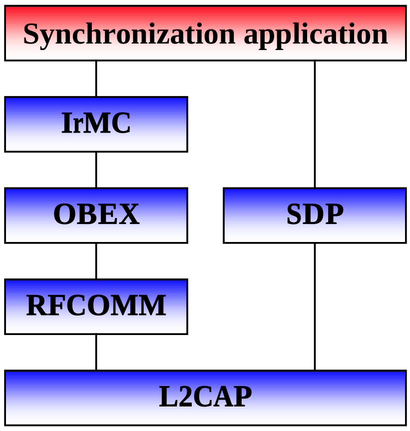

Figure 6 Protocol Stack for Synchronization

3.5 Three-in-One Phone

Telephone handsets built to this profile may connect to three different service providers. First, telephones may act as cordless phones connecting to the public switched telephone network (PSTN) at home or the office and incurring a fixed line charge. This scenario [35] includes making calls via a voice basestation, making direct calls between two terminals via the basestation and accessing supplementary services provided by an external network. Second, telephones can connect directly to other telephones for the purpose of acting as a “walkie-talkie” or handset extension. Referred to as the intercom scenario [36], the connection incurs no additional charge. Third, the telephone may act as a cellular phone connecting to the cellular infrastructure and incurring cellular charges. The cordless and intercom scenarios use the same protocol stack, which is shown in Figure 7. The audio stream is directly connected to the Baseband protocol indicated by the L2CAP bypassing audio arrow.

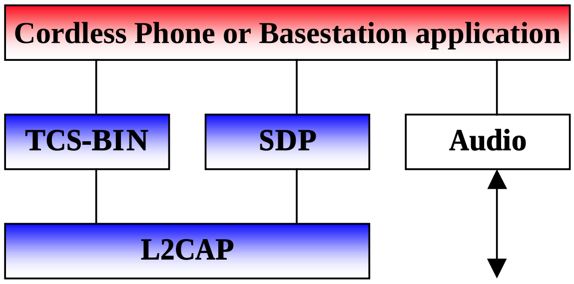

Figure 7 Protocol Stack for Cordless Phone and Intercom Scenarios

3.6 Ultimate Headset

The headset can be wirelessly connected for the purpose of acting as a remote device's audio input and output interface. The headset increases the user's freedom of movement while maintaining call privacy. A common example is a scenario where a headset is used with either a cellular handset, cordless handset, or personal computer for audio input and output. The protocol stack for this usage model is depicted in Figure 8 [7]. The audio stream is directly connected to the Baseband protocol indicated by the L2CAP bypassing audio arrow. The headset must be able to send AT-commands and receive result codes. This ability allows the headset to answer incoming calls and then terminate them without physically manipulating the telephone handset.

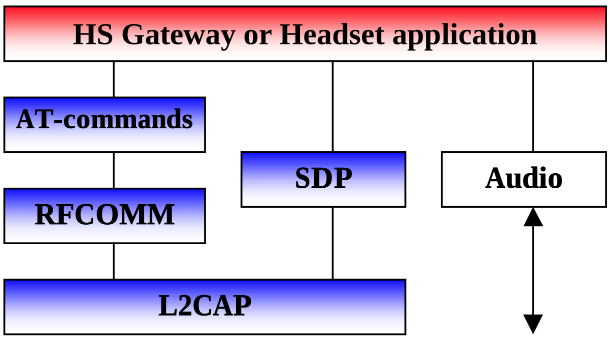

Figure 8 Ultimate Headset Protocol Stack

4 Summary

The Bluetooth protocols are intended for rapidly developing applications using the Bluetooth technology. The lower layers of the Bluetooth protocol stack are designed to provide a flexible base for further protocol development. Other protocols, such as RFCOMM, are adopted from existing protocols and these protocols are only modified slightly for the purposes of Bluetooth. The upper layer protocols are used without modifications. In this way, existing applications may be reused to work with the Bluetooth technology and the interoperability is ensured more easily.

The purpose of the Specification is to promote the development of interoperable applications targeted at the highest priority usage models identified by the SIG's marketing team. However, the Specification also services as a framework for further development. Naturally, vendors are encouraged to invent more usage models within this framework. Using the Bluetooth technology with the capabilities of current computers and communications devices, the possibilities for new future wireless applications are unlimited.

5 References

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[30] Bluetooth Special Interest Group, Service Discovery Application Profile

[31] Bluetooth Special Interest Group, Generic Object Exchange Profile

[32] Bluetooth Special Interest Group, File Transfer Profile

[33] Bluetooth Special Interest Group, Object Push Profile

[34] Bluetooth Special Interest Group, Synchronization Profile

[35] Bluetooth Special Interest Group, Cordless Telephony Profile

[36] Bluetooth Special Interest Group, Intercom Profile

6 Acronyms

Abbreviation or Acronym	Meaning
ACL	Asynchronous ConnectionLess
API	Application Programming Interface
CRC	Cyclic Redundancy Check
DT	Data Terminal
FEC	Forward Error Correction
FTP	File Transfer Protocol
GAP	Generic Access Profile
GOEP	Generic Object Exchange Profile
HCI	Host Controller Interface
HTTP	HyperText Transfer Protocol
IETF	Internet Engineering Task Force
IP	Internet Protocol
IrDA	Infrared Data Association
IrMC	Ir Mobile Communications
LAN	Local Area Network
LAP	LAN Access Point
LMP	Link Manager Protocol
L2CAP	Logical Link and Control Adaptation Protocol
OBEX	Object Exchange Protocol
PDA	Personal Digital Assistant
PIM	Personal Information Management
PPP	Point-to-Point Protocol
PSTN	Public Switched Telephony Network
RFCOMM	Serial Cable Emulation Protocol
SCO	Synchronous Connection-Oriented
SDAP	Service Discovery Application Profile
SDP	Service Discovery Protocol
TCP/UDP	Transport Control Protocol/User Datagram Protocol

Abbreviation or Acronym	**Meaning**
TCS Binary	Telephony Control Specification – Binary
WAE	Wireless Application Environment
WAP	Wireless Application Protocol
WML	Wireless Markup Language