

CEA Technical Paper

Home Network Wireless Technologies
Evaluation: Phase I Report
Comparison of Technology
Performance Characteristics to
Consumer Application Needs

07/2006



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R7 Home Network Standards Committee

WIRELESS TECHNOLOGIES EVALUATION:

**Comparison of
Technology Performance Characteristics
to
Consumer Application Needs**

PHASE 1 REPORT:

Survey of Existing and Imminent Wireless Technologies

June 2006

Table of Contents

1.	Executive Summary	1
2.	Introduction.....	1
3.	Goals Of The Project	1
4.	Organization Of This Report	2
5.	Home Networking Applications	2
5.1.	Typical Payload Bit Rate per Stream.....	6
5.2.	Streams per Connection	6
5.3.	1-Way Delay Considerations	6
5.4.	Round-Trip Delay Considerations	6
5.5.	Jitter Considerations.....	6
5.6.	Sensitivity to PER / PLR (3 Levels)	6
5.7.	Security Considerations	6
5.8.	Comments	6
6.	Data Summary	7
7.	Conclusions.....	19
7.1.	General Conclusions	19
7.2.	Conclusions about Applications of wireless technology	19
7.3.	Conclusions about the Data collected	20
7.4.	Additional Observations	21
7.4.1.	IEEE 802.11 Family.....	21
7.4.2.	Ultra Wide Band	21
7.5.	Other Factors to consider	21
7.6.	Consumer Expectations and the current Market.....	21
Annex A.	Methodology and Parameters	22
A.1.	Methodology Used To Prepare This Report	22
A.2.	Parameters and Characteristics Collected.....	23
Annex B.	IEEE 802.11b (WG7 effort).....	28
Annex C.	IEEE 802.11a/b/g].....	35
Annex D.	IEEE 802.11a	39
Annex E.	IEEE 802.11g.....	43
Annex F.	IEEE 802.15.1	47
Annex G.	IEEE 802.15.1a (Bluetooth).....	51
Annex H.	IEEE 802.15.3	55
Annex J.	IEEE 802.15.3a (proposed) – DS/UWB	60
Annex K.	IEEE 802.15.3a (proposed) – Multi-Band OFDM UWB	64
Annex L.	IEEE 802.15.4 (ZigBee)	68
Annex M.	IEEE 802.16 (WiMax)	72
Annex N.	HiperLAN2	76
Annex O.	List of Acronyms	80

CEA
R7 Home Network Standards Committee

**Wireless Technologies Evaluation: Comparison of
Technology Performance Characteristics to Consumer Application Needs**

**Phase 1 Report:
Survey of Existing and Imminent Wireless Technologies**

1. Executive Summary

This informative report is being provided by the Consumer Electronic Association's R7 Home Network Standards Committee, WG7 Wireless Home Network Working Group. This report identifies current consumer networking applications and the requirements those applications place on wireless in-home networks. The report places specific emphasis on entertainment applications, although other applications are discussed.

The information contained herein represents the consensus of the Working Group members who include leading consumer electronics manufacturers, service providers, wireless technology experts, and others interested in the subject matter. CEA and the R7 WG7 members welcome questions and comments from industry on this report and on any matters related to wireless in-home networks.

This report concludes Phase 1 of this work. Our Phase 2 work is intended to provide meaningful measurements that can be used to directly evaluate the different technologies for differing applications.

2. Introduction

The Consumer Electronics Association's Wireless Home Network Working Group (WG7) develops and maintains standards related to in-home wireless networks for consumer electronics applications. WG7 addresses subject matter relating to wireless devices and wireless networks for inclusion into consumer home networks. Currently the group is tasked with identifying uses of wireless technologies in AV networks and assessing their associated performance requirements. The group has produced this survey report of wireless technology options and reported to the R7 Home Network parent committee.

WG7 spent considerable time investigating wireless technologies and identifying common applications found on wired networks that could also be deployed on wireless networks. It is the CEA's view that moving these applications into a wireless network environment will provide an "ease of use" benefit to the consumer. However, the applications are typically designed with the assumption of a reliable transport, providing continuous connectivity, negligible bit error rate, constant transmission rate, etc. Wireless networks, especially those in unlicensed bands, do not provide the same reliability or bandwidth as wired networks.

3. Goals Of The Project

The scope of the first phase of WG7's work is to "Identify uses of wireless technologies in A/V networks and assess their associated performance requirements. Survey wireless technology options and report to R7." This report is the output of Phase 1 of WG7's efforts.

WG7 members believe that the identification of issues arising from the emergence of wireless home networking is the first step towards the development of standards and consumer education materials that will assist the wide acceptance of the technology.

The goal of this report is to provide meaningful specifications to help the product developer choose the correct wireless technology for a given application, to determine the application's need for transport modification for use with a given wireless technology, and to create reasonable assumptions about the level of performance that can be expected from a given wireless technology when used with a specific application.

Now that the report is complete, WG7 intends to develop standards that will allow consistent measurements to be made for all wireless technologies (Phase 2). During Phase 2 WG7 will:

- identify the parameters from Phase 1 that require clarification;
- describe measurement methods for related variables (such as range versus throughput versus error rates);
- study QoS requirements;
- and consider how best to constrain and represent environmental influences on network performance (construction, impairment sources).

These efforts will be affected by revised specifications, and required network interoperability and spectrum non-interference.

4. Organization Of This Report

This document contains a discussion of home networking applications, a survey of wireless technologies, conclusions about the survey, a glossary of terms, three tables and a number of annexes.

Table 1 lists applications and their requirements for transport on a network. The intent of this table is to inform network architects and developers about the constraints that a given application requires from a network in order to work reliably.

Table 2 summarizes the results of the technology survey. Similar attributes were collected, and each technology is described.

Annex A describes the report methodology and wireless attributes that were surveyed. The row headings have been carefully identified and the working group has reached consensus that these attributes characterize the important capabilities of wireless network technologies for use in an in-home network. Careful consideration has been given to the specification entries of the annexes.

The remainder of the annexes contains the results of a survey of wireless technologies and their specifications based on open standards. Information received during the summer of 2004 was used to prepare these annexes. In some cases, because the technologies are still under development, the information in the annexes may be out of date. Readers are encouraged to contact WG7 if they identify errors in or corrections to any of the information presented.

5. Home Networking Applications

Home Networking applications can be roughly characterized in terms of these requirements or their combinations:

- Bandwidth Requirements
- Sensitivity to Delays and / or Jitter
- Sensitivity to Errors
- Security Requirements

For example: Telephony (such as Voice-Over-IP) has low bandwidth requirements but high sensitivity to delays and errors and must be secure (although there is no requirement for content copy-protection).

Video requirements vary based on the type of service - whether video is streaming to a display or being stored for future viewing; the level of security required; the displayed resolution of the content and other factors. Sensitivity to delay may be important if, for example, the application calls for frequent channel changes, or if the display device cannot buffer the data. Delay may be unimportant if the data is being stored or buffered. All video is sensitive to errors.

Table 1 organizes wireless technologies and associated characteristics in such a way that the application developer can understand the impact of a technology choice on their application. The Examples and Table 1 make clear the importance of defining the application fully in order to understand its requirements. No simple table is capable of detailing every possible usage model, but Table 1 provides a qualitative indication of the requirements within a range. It is left to the developer to manage the necessary tradeoffs.

An explanation of Table 1 column headings follows the table.

Applications	Typical Payload Bit Rate per Stream	Streams per Connection (number)	1-way Delay Considerations	Round trip Delay Considerations	Jitter Considerations	Sensitivity to PER /PLR (3 Levels)	Security Considerations	Comments
VIDEO								
Watching Broadcast TV (MPEG2)	3-20 Mbps ¹	1	Important for channel changing	Not important	Part of delay, tradeoff with buffer size	High - Some errors can be handled by buffering with retransmission – tradeoff with throughput	May be subject to content control mechanisms (e.g. retransmission flag)	
Interactive TV, Video on Demand (MPEG2 stream, separate control data)	3-20 Mbps	1	Important for channel changing	Important for user interactivity (control information needs timely response)	Part of delay. Tradeoff with buffer size.	High for video stream (see note on Broadcast TV). Low for control data (assumes robust protocols e.g. retransmission, FEC)	MPEG2 stream may be subject to content control mechanisms Encryption for financial transactions	Assumes separate control data for interactivity
Premium channels, Pay Per View (MPEG2)	3-20 Mbps	1	May be important for channel changing	Not important	Part of delay. Tradeoff with buffer size	High (See note on Broadcast TV).	May be required for copy protection, etc.	
Internet Video	28.8k – 1500k bps	1	Not important	Not important	Part of delay. Tradeoff with buffer size	Low if buffered High if live or multicast	May be required for copy protection, etc.	
Privately generated video	3-30 Mbps (30 Mbps is for Digital Video)	1	Not critical	Not important	Not important	High - Some errors can be handled by buffering with retransmission – tradeoff with throughput	Important for privacy	Camcorder

¹ CEA-775 has an option for multiplex streams up to 40 Mbps. Typical cable plants have limits up to 38.8 Mbps.

Applications	Typical Payload Bit Rate per Stream	Streams per Connection (number)	1-way Delay Considerations	Round trip Delay Considerations	Jitter Considerations	Sensitivity to PER /PLR (3 Levels)	Security Considerations	Comments
Security Camera	144 Kbps – 8 Mbps	1	Important for human factors	Important for human factors	Part of delay. Sensitive if 2-way communication is included Tradeoff with buffer size	Medium – useful information is in still frame content, human compensation techniques can be employed if needed	Important for privacy and chain of evidence	Privacy is inherent in security systems
Videophone	144 kbps (for ISDN)	2	Important for human factors	Important for human factors	Part of delay. Sensitive due to 2-way communication	High	Important for privacy	Assume audio and video are multiplexed into 1 stream
AUDIO								
Listening to radio, CD, MP3	128 kbps - 320kbps	1	Important for multi-room distribution	N.A.	Part of delay. Tradeoff with buffer size	High- Some errors can be handled by buffering with retransmission – tradeoff with throughput	May be required for copy protection	
Wireless Stereo Speakers	64kbps- 1.5Mbps	1	Very important for synchronization	N.A.	Sensitive due to need for short delay	High	May be required for copy protection	Assumes one stream, speaker will extract its channel
Home Theater Audio	384kbps – 4.5 Mbps	1	Very Important for synchronization	N.A.	Sensitive due to need for short delay	High	May be required for copy protection	Assumes one stream, speaker will extract its channel
Telephony	64 kbps	2	Important for human factors	Important for human factors	Part of delay. Sensitive due to 2-way communication	High	Important for privacy	
DATA								
Command/control	~8 kbps	N.A.	Important for resource management	N.A.	Part of delay. Tradeoff with buffer size	Low, uses retransmission	–Unknown	
Physical Security System	<250kbps	N.A.	Critical	3 - Sensor communications	N.A.	High – Some errors can be compensated for	May need encryption	Need to be reliable but not necessarily fast (need messages per second not bits per second)
Sensor communications				Not critical				

Applications	Typical Payload Bit Rate per Stream	Streams per Connection (number)	1-way Delay Considerations	Round trip Delay Considerations	Jitter Considerations	Sensitivity to PER /PLR (3 Levels)	Security Considerations	Comments
Physical Security System Administration & UI	~28.8 kbps – 1500kbps	N.A.	Important for human factors	Important for human factors	N.A.	Low, uses retransmission	Needs encryption	Need to be reliable but not necessarily fast (need messages per second not bits per second)
Physical Security System Alarm Reporting	1200 bps – reporting only 64 Kbps – listen in 256 kbps – look in	1 or 2	Important for human factors	Important for human factors	Part of delay. Sensitive if 2-way communication, audio, or video is included Tradeoff with buffer size	Low, uses retransmission	Needs authentication	Delays must be bounded (predictable) and reasonable in human time, but not really small
Game Controllers	8kbps	N.A.	Important for human factors	Important for user interaction	Sensitive due to need for short delay	High	Unknown	
Web browsing	~28.8 kbps – 1500kbps	N.A.	Not critical	Not critical	N.A.	Low, uses retransmission	May need encryption	Includes fax, email and financial transactions
Web hosting	28.8 kbps – 1500k bps	N.A.	Not critical	Not critical	N.A.	Low, uses retransmission	May need encryption	External access, internal hosting
Instant Messaging	28.8 kbps or greater	N.A.	Important for human factors	Important for human factors	N.A.	Low, uses retransmission	May need encryption	May include text and pictures
Interactive games	~8 kbps	N.A.	Important	Important	N.A.	High	May need encryption	Interconnected game consoles
Background Transfer - Cache Update	Limited by network congestion, file size, and user expectations	N.A.	Not important	Not important	N.A.	Low, uses retransmission	May need encryption	
Mobile Synch	~512 kbytes / 8sec = 0.5 Gbps	N.A.	Not critical	Not critical	N.A.	Medium (for efficiency)	Authentication and encryption	Will scale with evolving user expectations and device capabilities

Applications	Typical Payload Bit Rate per Stream	Streams per Connection (number)	1-way Delay Considerations	Round trip Delay Considerations	Jitter Considerations	Sensitivity to PER /PLR (3 Levels)	Security Considerations	Comments
Content Transfer – Movie	SD: 4 Gbytes / 600 sec = 13 Mbps HD: 20 Gbytes / 600 sec = 76 Mbps	N.A.	Not critical	Not critical	N.A.	Low, uses retransmission	May need encryption	Assumed user will wait up to 10 minutes
Content Transfer – Portable Memory	512 kbytes / 8sec = 0.5 Gbps	N.A.	Not critical	Not critical	N.A.	Low, uses retransmission	May need encryption	Assumed user will wait up to 8 seconds

Table 1 - Application Requirements**5.1. Typical Payload Bit Rate per Stream**

Indicates the actual throughput in million bits per second required by the application, not including protocol overhead, retransmission due to bit errors or lost packets, forward error correction overhead, etc.

5.2. Streams per Connection

Indicates the number of content streams required by the application. It is not a reflection of the requirement for 1-way or 2-way communication.

5.3. 1-Way Delay Considerations

1-Way Delay is the difference between the time a packet is sent by its source and the time the packet reaches its destination. Although this is a tightly specified value for some technologies, for others it can vary widely according to the amount and types of data traffic. The column indicates special considerations that need to be taken into account.

5.4. Round-Trip Delay Considerations

For applications that require bi-directional streams or responses to a request, the total delay in both directions may be important.

5.5. Jitter Considerations

The short-term timing variations in the delay from packet to packet.

5.6. Sensitivity to PER / PLR (3 Levels)

PER is Packet Error Rate and is the rate at which errors in transmission/reception result in the rejection of a packet. PLR is the Packet Loss Rate and is equivalent to PER for our purposes.

5.7. Security Considerations

Security methods range from Encryption to render the data unreadable by unauthorized devices, to Authentication which ensures that a device describes itself correctly. There are also differing levels of security; this column indicates the types of security that an application may require.

5.8. Comments

Provides additional clarifying information.

6. Data Summary

A summary of the data collected is shown in Table 2. For each technology summarized in Table 2, the detailed data is contained in an annex at the end of this report.

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
General Comments (about the attribute)	* These are spread spectrum technologies (TDMA or frequency hopping)	<u>Throughput:</u> Approximate values are given; some are derived or interpreted, most from measured values in field conditions. Actual rate could be greater, but it depends on various other factors. Link rate is not provided because it's not as useful at the application level.	** All can send asynchronous messages (even with a clock, not all packets need to be sent at every clock cycle). Priorities are tied to asynch traffic. ** All are or can be Deterministic. All have parameterized capability.	*** All have phy level FEC. Some have block FEC (MAC level): 802.15.1, 802.15.1a, Bluetooth, and HL2 do have FEC In extreme cases, frequency hopping technologies appear like narrow band (if they avoid too many frequencies).	Asynch delays are always subject to network loading (traffic volume and number of nodes). Parameterized (including isochronous) delays are not sensitive to loading. Delay and jitter need to be measured under the same conditions.	Authentication optional for all technologies.	Modes include...	

**Table 2 - Phase 1 Data Summary Chart:
Technology Characteristics v. Application Attributes**

(continued below)

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
WIFI a IEEE 802.11a	5GHz, 23 20MHz RF Channels	<u>Throughput:</u> 30 Mbps <u>Range:</u> 150 ft (at 6Mbps and through several walls) <u>Roaming:</u> implementation specific	Provided by the new 802.11e Prioritized (mandatory, WMM) and Parameterized (optional, WMM-SA)	<u>Errors:</u> Retransmission at the MAC level. <u>Multipath:</u> Handled by OFDM equalization and antenna diversity. <u>Coexistence:</u> Dynamic channel selection (11h) for other network types, collision avoidance for other “a” networks <u>In-band noise:</u> Alters modulation method and sacrifices throughput. <u>Loading:</u> No sensitivity to nodes being added, but network access slows as nodes increase traffic.	(11e not included) <u>1-Way (max):</u> Asynch: 2.4 ms (no loading) <u>Round Trip (max):</u> Asynch: 4.8 ms (no loading) – twice the 1-way delay <u>Jitter:</u> (taking from 11b data) Asynch: ~700 us (no loading) but depends on network loading (collisions)	<u>Admission:</u> Open, shared key. <u>Authentication:</u> Provided by 802.1x, variety of mechanisms. <u>Encryption:</u> Legacy uses WEP, replaced by WPA, 802.11i defines WPA2	<u>Topology:</u> Ad Hoc, Infrastructure, Infrastructure with multiple APs (non-standard?), Managed Peer-to-Peer (Direct Link per 802.11e) Bridging is non-standard <u>Nodes:</u> per AP: 2007 (protocol) per AP: 64-128 (practical) <u>Modes:</u> See topologies Can also use RTS/CTS to deal with hidden nodes	

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
WIFI b IEEE 802.11b	2.4GHz, 11 20MHz RF Channels (overlapping)	<u>Throughput:</u> 6 Mbps <u>Range:</u> 45m/6.3Mbps (2 devices) 45m/2.1Mbps (access point and 3 devices) <u>Roaming:</u> implementation specific	Provided by the new 802.11e Prioritized (mandatory, WMM) and Parameterized (optional, WMM-SA)	<u>Errors:</u> Retransmission at the MAC level. <u>Multipath:</u> Handled by antenna diversity. <u>Coexistence:</u> Dynamic channel selection for other network types, collision avoidance for other “b” and “g” networks <u>In-band noise:</u> Alters modulation method and sacrifices throughput for tolerance to in-band noise. <u>Loading:</u> No sensitivity to nodes being added, but network access slows as nodes increase traffic.	(11e not included) (increased by RTC/CTS) <u>1-Way (max):</u> Asynch: >2.4 ms (no loading) <u>Round Trip (max):</u> Asynch: >4.8 ms (no loading) - twice the 1-way delay <u>Jitter:</u> Asynch: ~700us (no loading) but depends on network loading (collisions)	<u>Admission:</u> Open, shared key. <u>Authentication:</u> Provided by 802.1x, variety of mechanisms. <u>Encryption:</u> Legacy uses WEP, replaced by WPA, 802.11i defines WPA2	<u>Topology:</u> Ad Hoc, Infrastructure, Infrastructure with multiple APs (non-standard?), Managed Peer-to-Peer (Direct Link per 802.11e) Bridging is non-standard <u>Nodes:</u> per AP: 2007 (protocol) per AP: 64-128 (practical) <u>Modes:</u> See topologies Uses RTS/CTS to deal with hidden nodes	

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
WIFI g IEEE 802.11g	2.4GHz, 11 20MHz RF Channels (overlapping)	<u>Throughput:</u> 30 Mbps <u>Range:</u> 150 ft (at 6Mbps and through several walls) <u>Roaming:</u> implementation specific	Provided by the new 802.11e Prioritized (mandatory, WMM) and Parameterized (optional, WMM-SA)	<u>Errors:</u> Retransmission at the MAC level. <u>Multipath:</u> Handled by OFDM equalization and antenna diversity. <u>Coexistence:</u> Dynamic channel selection for other network types, collision avoidance for other “b” and “g” networks. <u>In-band noise:</u> Alters modulation method and sacrifices throughput for tolerance to in-band noise. <u>Loading:</u> No sensitivity to nodes being added, but network access slows as nodes increase traffic. <u>Other:</u> Friendly to legacy in same family (g down shifts to b) but at slower speeds.	(11e not included) (g only is better than g/b due to RTS/CTS) <u>1-Way (max):</u> Asynch: 2.4ms (no loading) <u>Round Trip (max):</u> Asynch: 4.8ms (no loading) - twice the 1-way delay <u>Jitter:</u> (taking from 11b data) Depends on network loading (collisions)	<u>Admission:</u> Open, shared key. <u>Authentication:</u> Provided by 802.1x, variety of mechanisms. <u>Encryption:</u> Legacy uses WEP, replaced by WPA, 802.11i defines WPA2	<u>Topology:</u> <ul style="list-style-type: none"> ▪ Ad Hoc, Infrastructure ▪ Infrastructure with multiple APs (non-standard?) ▪ Managed Peer-to-Peer (Direct Link per 802.11e) Bridging is non-standard <u>Nodes:</u> per AP: 2007 (protocol) per AP: 64-128 (practical) <u>Modes:</u> See topologies Can interoperate with 802.11b at lowers speed in “b” mode and uses RTS/CTS to deal with hidden nodes Can also extend range in a “g” only network by fallback to “b” mode.	

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
IEEE 802.15.1	2.4GHz, degrades beyond 9 piconets in close proximity *	<u>Throughput:</u> 700 Kbps <u>Range:</u> 10m (specified and anecdotal) <u>Roaming:</u> No roaming, intended as PAN	No priorities Parameterized (SCO links) Clock provided by piconet master controller (SCO links are synchronous but not isochronous)	<u>Errors:</u> Many FECs available (some optional). <u>Multipath:</u> frequency hopping <u>Coexistence:</u> Transmit power control for coexistence with other WLANS. Up to 9 piconets coexist well. <u>In-band noise:</u> transmit power control <u>Loading:</u> Piconet controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way (max):</u> SCO links: 1.25ms (typical loading) <u>Round Trip (max):</u> SCO links: 1.9ms (typical loading) <u>Jitter:</u> 10us (max)	<u>Admission:</u> Per piconet controller E22 (key generator) <u>Authentication:</u> Done at link layer <u>Encryption:</u> E0 (stream cipher): Algorithm uses 128 bit key, 48 bit device address, master clock, and 128 bit random value.	<u>Topology:</u> Infrastructure (all communication to/from Piconet controller) <u>Nodes:</u> per piconet master: 7 active nodes and 250 parked nodes (standby nodes not part of a piconet) <u>Modes:</u> SCO and ACL value.	Speak when spoken to

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
IEEE 802.15.1a	2.4GHz, degrades beyond 9 piconets in close proximity *	<u>Throughput:</u> 700 Kbps (total) 64 Kbps (per SCO link) <u>Range:</u> 10m (specified and anecdotal) <u>Roaming:</u> No roaming, intended as PAN	No priorities Parameterized Clock provided by piconet master controller (SCO links are synchronous but not isochronous)	<u>Errors:</u> Many FECs available (some optional). Retransmission at the MAC level. <u>Multipath:</u> adaptive frequency hopping <u>Coexistence:</u> Transmit power control and adaptive frequency hopping for coexistence with other WLANS. Up to 9 piconets coexist well. <u>In-band noise:</u> Adaptive frequency hopping. (Avoids frequencies of in-band interferers and sacrifices number of coexisting networks). <u>Loading:</u> Piconet controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way (max):</u> SCO links: 1.25ms (typical loading) <u>Round Trip (max):</u> SCO links: 1.9ms (typical loading) <u>Jitter:</u> 10us (max)	<u>Admission:</u> Per piconet controller E22 (key generator) <u>Authentication:</u> Done at link layer <u>Encryption:</u> E0 (stream cipher): Algorithm uses 128 bit key, 48 bit device address, master clock, and 128 bit random value.	<u>Topology:</u> Infrastructure (all communication to/from Piconet controller) <u>Nodes:</u> per piconet master: 7 active nodes and 250 parked nodes (standby nodes not part of a piconet) <u>Modes:</u> SCO and ACL	
Bluetooth Like IEEE 802.15.1a, except LLC is different						Additional features	LLC different	

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
IEEE 802.15.3	2.4GHz, 4 15MHz RF Channels	<p><u>Throughput:</u> 42 Mbps</p> <p><u>Range:</u> 61m (at 55 Mbps)</p> <p>102m (22 Mbps)</p> <p><u>Roaming:</u> Implementation specific and with Mesh topology</p>	<p>Prioritized and Parameterized</p> <p>Isochronous</p>	<p><u>Errors:</u> Retransmissions at MAC level</p> <p><u>Multipath:</u> Handle by equalizers.</p> <p><u>Coexistence:</u> Dynamic channel selection, transmit power control, and a variety of other methods for coexistence with other WLANs.</p> <p><u>In-band noise:</u> Can schedule around periodic interferers.</p> <p><u>Loading:</u> Piconet controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.</p>	<p><u>1-Way (max):</u> Asynch: <65ms (typical loading)</p> <p>Isoch: <10ms (typical loading, and by requesting channel allocation)</p> <p><u>Round Trip (max):</u> Isoch: <65ms (typical loading)</p> <p><u>Jitter:</u> Isoch: 30us (frame boundary)</p>	<p><u>Admission:</u> Per piconet controller</p> <p><u>Authentication:</u> Done at higher layers (AES-CCM)</p> <p><u>Encryption:</u> AES-CCM (128 bit key)</p>	<p><u>Topology:</u></p> <ul style="list-style-type: none"> Peer-to-Peer Ad Hoc Managed Peer-to-Peer Mesh (data exchange only, per 802.15.5) Infrastructure mode (Star) Bridged Peer-to-Peer (data exchange only) <p><u>Nodes:</u> 236 (protocol)</p> <p><u>Modes:</u> Shadow controller</p> <p>1394 PAL</p>	<p>Capabilities fall generally in between WIFI and Bluetooth (802.11 and 802.15.1)</p> <p>Standard was developed for multi-media applications.</p>

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
UWB/ OFDM Proposed IEEE 802.15.3a	3.1-4.75 GHz, 6 Piconets in mandatory mode * 3.1-10.6GHz, (4 groups of 3, and 2 more – 28 total ?) *	<u>Throughput:</u> 460 Mbps (derived from reported throughput and link rate) <u>Range:</u> 11m (at 105 Mbps) 3.5m (at 460 Mbps) <u>Roaming:</u> Implementation specific and with Mesh topology	Prioritized and Parameterized Isochronous	<u>Errors:</u> No MAC level FEC for FDM mode. Retransmissions at MAC level <u>Multipath:</u> Handle by OFDM equalizers in FDM mode. <u>Coexistence:</u> Low power spectral density, as well as dynamic channel selection, transmit power control, and a variety of other methods for coexistence with other WLANs. <u>In-band noise:</u> Phy layer robust coding, erasure coding (notches), spectral spreading, and interleaving for tolerance to in-band noise. (sacrifice throughput or error rate) <u>Loading:</u> Piconet controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way (max):</u> ? <u>Round Trip (max):</u> ? <u>Jitter:</u> Isoch: 30us (frame boundary)	<u>Admission:</u> Per piconet controller <u>Authentication:</u> Done at higher layers (AES-CCM) <u>Encryption:</u> AES-CCM (128 bit key)	<u>Topology:</u> ♦ Peer-to-Peer ♦ Ad Hoc ♦ Managed Peer-to-Peer ♦ Mesh (data exchange only, per 802.15.5) ♦ Infrastructure mode (Star) ♦ Bridged Peer-to-Peer (data exchange only) <u>Nodes:</u> 236 (protocol) <u>Modes:</u> Separate modes: FDM (mandatory) and TFC (for multiple networks) 1394 PAL	Responses received were based on the proposal made to the IEEE 802.15.3a committee. (See section 7.4.2)

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
UWB/DS Proposed IEEE 802.15.3a	3.1-5GHz, 6 Piconets * 6-10.6, 6 Piconets *	<u>Throughput:</u> 750 Mbps <u>Range:</u> 10m (at 85 Mbps) 2m (at 750 Mbps) <u>Roaming:</u> Implementation specific and with Mesh topology	Prioritized and Parameterized Isochronous	<u>Errors:</u> Retransmissions at MAC level <u>Multipath:</u> Handle by equalizers, spreading codes, and coherent wide bands. <u>Coexistence:</u> Dynamic channel selection, transmit power control, and a variety of other methods for coexistence with other WLANs. <u>In-band noise:</u> Equalizers, spreading codes, and coherent wide bands for tolerance to in-band noise. Can schedule around periodic interferers. (sacrifice throughput or error rate) <u>Loading:</u> Piconet controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way Delay:</u> ? <u>Round Trip Delay:</u> ? <u>Jitter:</u> Isoch: 30us (frame boundary)	<u>Admission:</u> Per piconet controller <u>Authentication:</u> Done at higher layers (AES-CCM) <u>Encryption:</u> AES-CCM (128 bit key)	<u>Topology:</u> ♦ Peer-to-Peer ♦ Ad Hoc ♦ Managed Peer-to-Peer ♦ Mesh (data exchange only, per 802.15.5) ♦ Infrastructure mode (Star) ♦ Bridged Peer-to-Peer (data exchange only) <u>Nodes:</u> 236 (protocol) <u>Modes:</u> 4 discreet speeds available 1394 PAL	Responses received were based on the proposal made to the IEEE 802.15.3a committee. (See section 7.4.2)

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
IEEE 802.15.4	900MHz, 10 2MHz RF Channels 2.4GHz, 16 5MHz RF Channels	<u>Throughput:</u> 150 Kbps (throughput not a preferred metric) (for both bands and both QoS modes) <u>Range:</u> 10m (at 150 Mbps, 2.4 GHz, indoor environment) 1000m (at 40 Mbps, 900 MHz, line of sight) <u>Roaming:</u> No roaming	No priorities Parameterized Synchronous, but not isochronous (no time stamps) Deterministic (contention access period)	<u>Errors:</u> No block FEC. Automatic retransmission. <u>Multipath:</u> Handle mostly by wave shape and pulse width. <u>Coexistence:</u> Low duty cycle, dynamic channel selection, transmit power control, and a variety of other methods for coexistence with other WLANs. <u>In-band noise:</u> See Coexistence. <u>Loading:</u> No sensitivity to nodes being added. Network access slows as nodes increase traffic, but has low duty cycle and supports GTS for particular nodes. <u>Other:</u> chipping sequence, good for battery life	<u>1-Way (max):</u> TDMA mode: 15ms (between time slots) CSMA mode: Depends on network topology and loading. <u>Round Trip (max):</u> TDMA: 30ms (twice 1-way) <u>Jitter:</u> TDMA: low CSMA: max could be infinite, depends on network topology and loading	<u>Admission:</u> Per piconet controller <u>Authentication:</u> Done at higher layers <u>Encryption:</u> AES-CCM (128 bit key), plus additions, total of 7 encryption and data integrity modes	<u>Topology:</u> <ul style="list-style-type: none"> ▪ Bridged peer-to-peer (peer-to-multi-peer) ▪ Managed peer-to-peer ▪ Ad hoc ▪ Mesh ▪ Cluster tree (modified star) <u>Nodes:</u> 2^64 <u>Modes:</u> TDMA and CSMA modes (can be both simultaneously for different channels on the same network)	Speak when spoken to
ZigBee Adds higher levels to IEEE 802.15.4 phy and MAC								Tradeoff between security and power consumption.

Table 2: Data Summary

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
WiMAX IEEE 802.16	2.4GHz, (4 20MHz or 8 10MHZ assumed) 5.1-5.35GHz, (10 20MHz or 20 10MHZ assumed) channel assignment varies by implementation	<u>Throughput:</u> 35 Mbps theoretical (10MHz channel) 70 Mbps theoretical (20 MHz channel) <u>Range:</u> 300m (at 70 Mbps, 20 MHz) 1Km (at 23 Mbps, 20 MHz, with beam forming) <u>Roaming:</u> Roaming is nomadic	Prioritized (classes are implemented at the convergence layer) Parameterized Isochronous (precise clock synchronization provided) Deterministic (admission control done above the MAC but enforced by the MAC)	<u>Errors:</u> Phy downshifts (changes modulation) when BER exceeds threshold <u>Multipath:</u> Mitigated by OFDM phy <u>Coexistence:</u> Dynamic channel selection, transmit power control, beamforming (optional), and a variety of other methods for coexistence with other WLANs <u>In-band noise:</u> Mitigated by OFDM phy and optional beamforming <u>Loading:</u> Base station controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way (max):</u> Asynch: <25ms (typical loading) Isoch: <10ms (typical loading, and by requesting channel allocation) <u>Round Trip (max):</u> Asynch: ? Isoch: ? <u>Jitter:</u> 2-20ms (phy frame size)	<u>Admission:</u> Per base station controller when nodes join <u>Authentication:</u> X.509 <u>Encryption:</u> DES/3DES AES-CCM (128 bit key)	<u>Topology:</u> ▪ Point-to-Multi-point (mandatory) ▪ Mesh (optional) but not for indoor use, indoor mesh being developed <u>Nodes:</u> 1600 (protocol) 1024 (practical) <u>Modes:</u> QPSK QAM 16 QAM 64	Received information pertained to residential application Speak when spoken to?

Technology (Common Name, Standard Number)	US Frequency Bands Channelization Number of Close Proximity Networks (User Channels)	Max Throughput (Payload Bit Rate) Range Characteristics (Coverage Area, Roaming)	QoS Characteristics (Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	Robustness (Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	Delay Characteristics (1-Way, Round Trip, Jitter)	Security Characteristics (Admission, Authentication, Encryption)	Network Topologies Number of Nodes Supported Modes of Operation	General Comments (about the technology)
HiperLAN2 ETSI TR 101 683	5GHz, 23 20MHz RF Channels	<u>Throughput:</u> 50 Mbps <u>Range:</u> 8m (at 50 Mbps, no walls) 30m (at 25 Mbps, 4 walls) <u>Roaming:</u> No roaming	Parameterized Prioritized Isochronous (provided through convergence layers)	<u>Errors:</u> MAC level FEC included (Reed Solomon) for packet errors. No retransmissions. <u>Multipath:</u> Handle by OFDM equalizers. <u>Coexistence:</u> Dynamic channel selection, transmit power control, and a variety of other methods for coexistence with other WLANs. <u>In-band noise:</u> Alters modulation method and sacrifices throughput for tolerance to in-band noise. <u>Loading:</u> Central controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way (max):</u> Asynch: 8 ms (typical) Isoch: 6 ms <u>Round Trip (max):</u> At least twice the 1-way delays. <u>Jitter:</u> Isoch: 6ms (application level)	<u>Admission:</u> Per central controller when node joins. <u>Authentication:</u> Managed by the central controller <u>Encryption:</u> DES (168 bit key)/3DES	<u>Topology:</u> <ul style="list-style-type: none"> ▪ Managed Peer-to-peer (for 1394 convergence layer) ▪ Infrastructure (for Ethernet convergence) <u>Nodes:</u> 20 <u>Modes:</u> 1394 convergence layer, Ethernet convergence layer	

7. Conclusions

7.1. *General Conclusions*

Wireless technology can create networks (WLAN - where distinct devices communicate among themselves) and enable cordless applications (WPAN - where subsidiary devices provide additional capabilities to a central device). Some technologies are designed primarily for one but can adapt to the other scenario.

Multiple technologies will need to coexist in a consumer environment because no technology can be optimized for every application and intended coverage area (WPAN to WLAN to WMAN to WWAN). Marketing assertions can distort the technical details of wireless technologies.

“Merge” technologies that can cross coverage areas may experience different market forces than technologies targeted to a particular application. These market forces can lead to advances in as well as sub-optimal applications of these technologies.

In general, technologies designed to create networks need common standards, whereas cordless applications can withstand proprietary implementations.

New or additional capabilities may be added to standards through the use of Extensions. (For example, security may not be viewed as necessary for all applications, but its inclusion can add value).

Technologies have mechanisms for dealing with various environments: these include “tuning”, use of multiple access points, directional antennas, extensions or other optional features for successful deployment in a particular environment. Developers must understand the kinds of environmental impairments encountered in common deployments.

The specific needs of WLAN technology integrators and installers are not directly addressed by this report. (Environmental impairments are expected to be addressed by the WG phase 2 efforts.) Developers of wireless applications are encouraged to address installation issues in their product support. This may include creation of installation guides.

7.2. *Conclusions about Applications of wireless technology*

It is not the goal of WG7 to design systems; that is left to the product implementers. System recommendations would need to be case by case, per application and per technology.

Some conclusions can be made based on examining the applications in Table 1 and the data from the annexes.

First, wireless networks have inherent limitations such as available throughput and error performance when compared with wired networks. Therefore developers of wireless network products will be forced to make tradeoffs based on the applications addressed and the technology selected. Table 1 and the annexes are intended to be used together to simplify the pairing of applications with wireless technologies. For example, a wireless solution must meet very stringent requirements in most of the categories in Table 1 if it is chosen for a general-purpose entertainment network supporting multiple applications (such as HDTV, home-theater audio and telephony).

Second, the product developer must take into consideration the attributes of the problem they are using wireless methods to solve. The wide range of requirements for many applications shown in Table 1 illustrates this point. Decisions made will affect the overall quality and reliability the product developer is able to achieve. As an example of the tradeoffs that must be managed, the Typical Payload Bit Rate per Stream for watching broadcast TV is 3-20 Mbps. This range of values takes into account video resolutions ranging from standard to high definition as well as different compression levels. Although buffering can offset variations in delay and jitter, and help to minimize the effects of bit errors by allowing a technology without forward error correction to retransmit packets, buffering is a tradeoff against the delays the user would encounter, for example, when changing channels. (The buffer may take some seconds to fill each time the channel is changed, resulting in a delay before the user sees the next channel.)

Using the Table 1 “Watching Broadcast TV” example, security may not be required if the content does not require copy protection. However, much content is, or will be protected, which will increase the need for security mechanisms. For a product targeting the distribution between rooms of copy-protected HDTV video (20 Mbps), streamed live from a set-top-box along with high quality audio (additive throughput), in a target market that expects the ability to channel surf between HDTV channels (low PER/PLR, low 1-way and round trip delay), the technology must support the higher end of the requirements. If that product must also support additional streams or data, the requirements become even more stringent.

Third, the developer must have an in-depth knowledge of the selected wireless technology. This is necessary to understand its capabilities, and the tradeoffs those capabilities will impose on the end product and ultimately its ability to meet the expectations of the consumer. The annexes will allow the product developer to narrow the potential solutions but they cannot provide the detail necessary to fully understand the tradeoffs that a technology may impose on a specific product implementation.

Whether wireless technology is operating in a licensed or an unlicensed band will affect the system. All technologies described in this report currently operate in unlicensed bands, and thus must balance characteristics such as raw performance for coexistence with other users of the band. Technologies operating in licensed bands may be expected to find a different balance.

Most wireless technologies studied by the WG have been deployed “randomly” by individuals and in localized areas. As more and more people adopt wireless technology, spectral bands get popular, then crowded. This changes the way the technology is perceived – early adopter experiences may differ from later adopters. Wireless technology deployment by service providers may cause immediate, large-scale changes to the environment. These trends may increase the requirements for coexistence over time. (Coexistence includes coexistence with other wireless technologies, and coexistence with other users of the same technology.) Coexistence strategies vary among technologies. (See Table 1 and the Annexes) In the extreme, this crowding may someday lead to changes in policy that remove regulatory approval for more “wasteful” and “ill-behaved” technologies.

7.3. *Conclusions about the Data collected*

In most cases, WG7 received responses from experts in each of the technologies who are involved in applying those technologies to existing problems. We believe that this process provided the best information available, but we are cautious about potential inadvertent bias in the data. WG7 would have liked to see data from field measurements. However, because of the differences in maturity in the technologies, some information comes from “real-life” measurements or anecdotal experiences with fielded technology, some from controlled “laboratory” measurements, and some from predictions about how technology should behave once it is deployed.

The reader is cautioned that technologies may have changed since the data was compiled.

Some data covers immature technologies that are changing - when products are launched they will implement a different version of the technology. Conclusions about suitability may change as the technologies evolve.

In some cases jitter and delays were not reported for the same operational conditions, so drawing meaningful conclusions was difficult. In Phase 2, jitter and delays should be measured under the same conditions.

In general, a centrally managed network uses bandwidth more efficiently than an unmanaged network. This might benefit some applications.

Different MAC layers have different overheads (some changing dynamically); the network behavior is expected to depend in part on this overhead.

In many technologies, range and throughput are linked. For all technologies, errors go up as range increases. To compensate for this effect, some technologies will “downshift” into a more robust encoding, or will decrease the attempted data rate. Not all technologies have this feature.

Hidden nodes are common to many technologies. Strategies vary on how to deal with the problem.

Coverage area is related to range, antenna design, and a specific installation environment. In general, as range goes up or throughput goes down, the potential coverage area will increase.

7.4. Additional Observations

New breakthroughs will be necessary, for example, when crowding makes legacy technologies unsatisfactory. As technologies evolve, maintaining backward compatibility is important to avoid the disenfranchisement of users. This graceful evolution of technologies is expected and a good thing. Evolution is driven by standardization and by market forces, and this evolution can in turn drive new standards and create new markets. The importance of graceful evolution increases as the deployed base increases.

Too much change confuses users, who are already dealing with rapidly evolving technologies such as displays – aspect ratios, HDTV/SDTV, LCD vs. Plasma, the conversion from analog to DTV, etc.

7.4.1. IEEE 802.11 Family

802.11b has been the subject of many papers. The 802.11 family of standards has had stable components for years, and continues to evolve. Many products have shipped from many vendors.

For better coexistence, 802.11b and 802.11g and Bluetooth (802.15.1) were extended on both sides.

7.4.2. Ultra Wide Band

The UWB responses received were based on the proposals made to the IEEE 802.15.3a committee. The data received describes UWB variants as PHY radio layers that increase throughput for 802.15.3 at the expense of range. WG7 understands wireless USB is a considered application for UWB but the standardization/codification efforts appear not to have advanced as much as the 802.15.3a work.

7.5. Other Factors to consider

Multiple networks (wired and wireless) are expected in most homes, as well as applications for distribution-only and point-to-point communications.

Trends and economics suggest some additional “merge” technologies are possible, e.g. cellular and 802.20, and 802.11n is expected, possibly 802.22

7.6. Consumer Expectations and the current Market

Current consumer applications for wireless networks include in-home transport of still pictures and audio. SD Video is beginning to be deployed.

Retailers have begun to offer free wireless installation.

Wireless is also being used as cord replacement for PDAs and cameras.

Annex A. Methodology and Parameters

A.1. Methodology Used To Prepare This Report

After Table 1 was created, WG7 began studying various wireless technologies and networks, identifying the important characteristics and parameters. See the following list of parameters and characteristics.

WG7 discussed how best to collect information for each technology; two approaches were attempted.

Approach 1 - 802.11b was chosen as the first technology for study. Groups of related parameters were studied by individual WG7 members and discussed during conference calls. Although 802.11b was suited to this method (since it is the most mature technology studied and WG7 members found many independent sources of information on each of the parameters), the cumulative time and effort required to learn the details of the technology meant that this report would have taken several years longer to prepare. The advantage to this approach was the creation of a set of references about the parameters studied. (See the annex for 802.11b).

Approach 2 - 802.15.3 was identified by WG7 as the second technology to be studied. A WG7 member is an expert on 802.15.3. That member collected and provided information on 802.15.3 in a short period of time. WG7 discussed and analyzed the response in one conference call.

After discussing the merits of the two approaches, WG7 concluded that a survey of experts would likely be the most efficient way to gather information on wireless technologies. WG7 prepared a request for information (RFI) and distributed it to CEA member companies. Responses were received over the next few months from knowledgeable sources, and WG7 discussed each response in a conference call. In some cases, multiple responses were received for the same technologies. During each call, follow-up questions were asked of the data submitters, and clarifications of the responses were developed by the committee.

During the process of analyzing some technologies, WG7 members realized that an additional characteristic (power consumption) was of importance to the effort. Questions about power consumption were drafted and distributed in early 2005. Not all of the original submitters provided answers to the follow up questions, so only the responses that were received are included in this report.

The tables in the later annexes of this report (Annex C-M) are the responses received, with clarifications and observations added by WG7.

Some of the most difficult work in discussing the technologies was populating the cells with meaningful information. In many cases, it is difficult to relate the wireless parameters to a home environment, and no standards exist. For example: if the “coverage area” parameter is defined in open space, it may have little or no relation to a home or apartment dwelling due to differing the propagation characteristics of radio waves in each environment.

Future such studies should take care to clearly, completely, and consistently define the parameters surveyed. WG7 hopes that its Phase 2 work will help with this problem. In particular, some important characteristics need better definition, including Delay, Jitter, and Sensitivity to Errors.

Many proprietary technologies also exist in the unlicensed bands. The methods used to create this report may be useful in analyzing them.

A.2. Sources of Responses

Data Sheet for IEEE 802.11a/b/g.....	from Texas Instrument
Data Sheet for IEEE 802.11a.....	from Atheros
Data Sheet for IEEE 802.11b.....	from Work Group (R7wg7)
Data Sheet for IEEE 802.11g.....	from Atheros
Data Sheet for IEEE 802.15.1.....	from Bluetooth SIG
Data Sheet for IEEE 802.15.1a.....	from Bluetooth SIG
Data Sheet for IEEE 802.15.3.....	from Appairnt
Data Sheet for IEEE 802.15.3a (proposed) – DS/UWB.....	from Motorola
Data Sheet for IEEE 802.15.3a (proposed) – Multi-Band OFDM UWB.....	from Intel
Data Sheet for IEEE 802.15.4.....	from ZigBee Alliance
Data Sheet for IEEE 802.16.....	from Cygnus
Data Sheet for HyperLAN2.....	from Thomson

A.3. Parameters and Characteristics Collected

Table 3 below describes the instructions given to RFP responders, and the fields shown in the following Annexes.

DATA SHEET LAYOUT:

Columns

Line # - sheet navigation reference (for location of row information on the technology data sheets)

Characteristic – a specific aspect of the technology

Performance – capability or limits of the technology, some specified and some typical implementations

Committee Comments – from work group discussions

End notes (at end of the data sheet)

Notes – additional detail for some characteristics

References – where data was obtained, individual or organization that provided the data, written sources used

GENERAL INSTRUCTIONS:

Modes of operation: If the technology is capable of multiple modes of operation, then the mode is to be specified for all measurements. Ideally measurements should be made for all modes (additional columns)

Network configuration: Describe what was on the network for each measurement that was made.

Repeatability: Disclose any other operational parameters necessary to repeat measurements.

SPECIFIC INSTRUCTIONS: (for each Characteristic)

Line #	Characteristic	Instructions
1.	Frequency Band:	Specify the frequency band used by the technology in each of these regions.
2.	USA	US Unlicensed Band Only
3.	Europe	European Unlicensed Bands only
4.	Japan	Japanese Unlicensed Bands only
5.	# of RF Channels:	Note total number of RF channels. Also note channel spacing necessary to avoid reduction in throughput.
6.	USA	US Unlicensed Band Only
7.	Europe	European Unlicensed Bands only
8.	Japan	Japanese Unlicensed Bands only
9.	Bandwidth per RF Channel:	Specify the maximum bandwidth (in (MHz) for each channel in the following regions.
10.	USA	US Unlicensed Band Only
11.	Europe	European Unlicensed Bands only
12.	Japan	Japanese Unlicensed Bands only
13.	Transmit Power (EIRP):	Specify maximum per appropriate government regulations. (Note: Measurement methodologies may differ in different regions, but the methodologies do not need to be specified.)
14.	USA	Specify maximum allowed
15.	Europe	Specify maximum allowed
16.	Japan	Specify maximum allowed
17.	Dynamic Transmit Power:	
18.	USA	Specify: Yes (with range), or No
19.	Europe	Specify: Yes (with range), or No
20.	Japan	Specify: Yes (with range), or No
21.	QoS:	
22.	Deterministic	State whether QoS is deterministic or not.
23.	Priority Classes	Specify: Yes (with number of channels) or No
24.	Parameterized	Specify: Yes or No
25.	Isochronous	Specify Yes or No (Note: This is a parameterized service that retains global clock distribution.)
26.	# of Isochronous Channels	Specify the protocol maximum
27.	Network Structure:	
28.	Topologies Enabled	Specify among the following possible topologies:

Line #	Characteristic	Instructions
		<ul style="list-style-type: none"> ▪ Bridged peer-to-peer or peer-to multi-peer, ▪ Ad Hoc, ▪ Managed peer-to-peer, mesh, ▪ Infrastructure mode (Star), ▪ Infrastructure mode (Star) with multiple APs, ▪ Infrastructure (Star) with repeater <p>If network topology differs between network coordination and data exchange, please note.</p>
29.	# of addressable nodes	Specify the protocol maximum
30.	Hidden nodes	Specify how the technology deals with hidden nodes
31.	Network Loading:	
32.	Network sensitivity when nodes are added	Not required but useful if available. Pertains to how network responds when additional nodes are added
33.	Network sensitivity to increased loading on existing nodes	Not required but useful if available. Pertains to how network responds when loading is increased on existing nodes.
34.	RF Channel Selection Method	Specify: Dynamic (continuous), Automatic (not continuous), Manual (user initiated), or None
35.	Interference (emission and tolerance):	
36.	Co-existence with other WLANs	Specify level of coexistence with the others in it's spectral allocation (not interoperability)
37.	Inherent Tolerance to in-band Interference	Specify how the technology deals with interference caused by other in band emitters
38.	Out of Band Noise Floor	Specify level of tolerance
39.	Speed:	
40.	Throughput (Asynchronous services)	Specify MAC payload throughput (report if this was with or without MAC level FEC and/or the limit set on the number of MAC level retransmissions). Also specify packet size and link rate. Describe environment measurements were taken in i.e. open field setting, home setting, etc. Specify number of nodes, infrastructure or ad hoc topology, MAC operational parameters, etc. Optional: specify bit error rate, packet error rate including dropped packets, packet size, power level, and link rate.
41.	Throughput (Isochronous services)	Specify MAC payload throughput (report if this was with or without MAC level FEC and/or the limit set on the number of MAC level retransmissions). Also specify packet size and link rate. Describe environment measurements were taken in i.e. open field setting, home setting, etc. Specify number of nodes, infrastructure or ad hoc topology, MAC operational parameters, etc. Optional: specify bit error rate, packet error rate including dropped packets, packet size, power level, and link rate.
42.	Network Join Time	Specify max time (up to layer 2 only, negotiation up to the point where the first

Line #	Characteristic	Instructions
		packet is sent)
43.	Link Rate	Specify theoretical maximum
44.	Range:	
45.	Coverage Area	Also specify bit error rate, packet error rate including dropped packets, packet size, MAC payload throughput (report if this was with or without MAC level FEC and/or the limit set on the number of MAC level retransmissions), power level, and link rate, for coverage area measurement. Describe environment measurements were taken in i.e. open field setting, home setting, etc.
46.	Delay (1 Way):	Delay due to transmitter and receiver MAC and physical layers (do not include transmit time for the data packet).
47.	Minimum Delay (Isoch Service)	Assumes channel has already been allocated.
48.	Maximum Delay (Isoch Service)	Assumes channel has already been allocated.
49.	Minimum Delay (Asynch Service)	For technology under ideal conditions with no other traffic
50.	Maximum Delay (Asynch Service)	Please specify network loading. Note the effects of arbitration mechanism if present.
51.	Jitter:	
52.	Jitter (Isoch Service)	Specify maximum inter-packet jitter or if different, define what your jitter value represents
53.	Jitter (Asynch Service)	Specify maximum inter-packet jitter or if different, define what your jitter value represents
54.	Delay (Round Trip):	Incremental MAC and physical layer delay added to a request/response round trip. This should include the turnaround time of the bus. Note if back channel is managed differently than forward channel (e.g. isoch vs. asynch).
55.	Minimum Delay (Isoch Service)	Assumes channel has already been allocated.
56.	Maximum Delay (Isoch Service)	Assumes channel has already been allocated.
57.	Minimum Delay (Asynch Service)	For technology under ideal conditions with no other traffic
58.	Maximum Delay (Asynch Service)	Please specify network loading. Note the effects of arbitration mechanism if present.
59.	Error Rates:	R7.7 need to review how to specify channel characteristics for BER, PER including free space, distance, traffic type, packet size, throughput, mode of operation, etc.
60.	Bit Error Rate	Also specify packet size, MAC payload throughput (report if this was with or without MAC level FEC and/or the limit set on the number of MAC level retransmissions), power level, and link rate, for bit error measurement. Describe

Line #	Characteristic	Instructions
		environment measurements were taken in i.e. open field setting, home setting, number of nodes, etc.
61.	Packet Error Rate	Also specify bit error rate, packet size, MAC payload throughput (report if this was with or without MAC level FEC and/or the limit set on the number of MAC level retransmissions), power level, and link rate, for packet error measurement. Describe environment measurements were taken in i.e. open field setting, home setting, number of nodes, etc.
62.	Security:	Note: This section applies only to security that is built-into the technology
63.	Admission	Specify methods used
64.	Authentication	Specify method used
65.	Encryption	Specify method used
66.	Integration:	
67.	Convergence Layers	Specify those technologies supported, e.g. Ethernet, 1394, etc.
68.	Component Availability	Specify: Yes (for available now) or Estimated Date
69.	Mobility:	
70.	Roaming	Specify method of native support by the technology, within the home LAN only, e.g. with multiple access points or nodes. This row is not addressing handoff which is being addressed by 802.21.
71.	Multipath Handling	Specify how it is handled (rejection method, mutipath signals used to enhanced performance, etc)
72.	Power Consumption:	State power in watts used by PHY/MAC layers as described in the standard. If this cannot be determined, state conditions in comment area - e.g. MAC/Phy functions performed off chip or higher layer functions performed on-chip. State also if this is a measured or estimated value.
73.	Idle State	receiver active, not transmitting
74.	Sleep Mode	state whether wake up is from network message, timer, or from external source e.g. system processor
75.	Max power consumption	Power used while transmitting at maximum power levels. State the link rate or transmission mode used e.g. QPSK, QAM 64, etc. State also Transmit power the measurement was made at.
76.	Min power consumption	Power used while transmitting at minimum power levels. State the link rate or transmission mode used e.g. QPSK, QAM 64, etc. State also Transmit power the measurement was made at.
77.	Other factors that affect power consumption	e.g. features or functions that are unique to this technology that affect power consumption and that are not included above such as sub-channelization; beamforming; on-chip functions that are typically accomplished off-chip; partial power down modes not listed above; etc.

Table 3 - Data Sheet Completion Instructions

Annex B. IEEE 802.11b (WG7 effort)

Line #	Characteristic	Performance	Committee Observations
1.	Frequency Band:		
2.	USA	2.4-2.4853 GHz (FCC 47CFR15.247)	
3.	Europe	2.4-2.4835 GHz (ETSI ETS 300-328)	
4.	Japan	2.4-2.4835 GHz (ARIB STD-T66)	
5.	# of RF Channels:		
6.	USA	3, with all 3 useable without reduction in throughput, spacing is at least 16 MHz	
7.	Europe	3, with all 3 useable without reduction in throughput, spacing is at least 16 MHz	
8.	Japan	3, with all 3 useable without reduction in throughput, spacing is at least 16 MHz	
9.	Bandwidth per RF Channel:		
10.	USA	20 MHz	
11.	Europe	20 MHz	
12.	Japan	20 MHz	
13.	Transmit Power (EIRP):		
14.	USA	4W EIRP, 1W with 6dBi antenna gain (FCC 15.247)	
15.	Europe	100mW (ERC/REC 70-03E) - limits on spectrum power density also	
16.	Japan	10mW/MHz (MPT Ordinance for Regulating Radio Equipment - Article 49-20)	
17.	Transmit Power (Dynamic):		
18.	USA	No	
19.	Europe	No	
20.	Japan	No	
21.	QoS:		
22.	Deterministic	Not at time of response.	802.11e completed in July 2005. (see end notes for 802.11 extensions)
23.	Priority Classes	Two priority classes: DCF and PCF. PCF is optional. [1, 2]	
24.	Parameterized	No [2]	
25.	Isochronous	No	
26.	# of Isochronous Channels	N/A	
27.	Network Structure:		
28.	Topologies Enabled	Infrastructure, Infrastructure with multiple APs, Ad-Hoc	
29.	# of addressable nodes	Theoretical limit is the Mac Address Space (2^{48} devices).	

Line #	Characteristic	Performance	Committee Observations
30.	Hidden node handling	CSMA/CA with special packets: request to send (RTS), clear to send (CTS), and acknowledge (ACK). This helps in certain situations but does not totally solve the hidden node problem. [3]	
31.	Network Loading:		
32.	Network sensitivity when nodes are added	Linear with new nodes as long as they are not hidden. Adding 10% hidden nodes can drastically reduce the efficiency. Hidden nodes can drop efficiency by 50% for data and 70% for video.	
33.	Network sensitivity to increased loading on existing nodes	Very sensitive to number of packets and size. It is also sensitive because of the various PHY's. One transmission at 1Mb/S because of transmitting a long distance can slow down the network.	
34.	RF Channel Selection Method	Manual	
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	Shares channel mapping with 802.11g. Supports 3 concurrent 802.11b channels without impacting throughput.	
37.	Inherent tolerance to in-band interference	Automatically alters modulation method to lower bit rates in the presence of interference.	
38.	Out of Band Noise Floor	$E < 500\mu\text{V/m}$	
39.	Speed:		
40.	Throughput (<i>Asynch</i>)	See ThroughputAsynch802.11b [4], [6]	
41.	Throughput (<i>Isoch</i>)	N/A	
42.	Network Join Time	Unknown (research needed)	
43.	Link Rate	11mbps	
44.	Range:		
45.	Coverage Area		
46.	Delay (1 Way):		
47.	Min (<i>Asynch</i>)	See 802.11 Timing Sheet, Table B-1 and Figure B-1 for Minimum Delay Timing using CSMA/CA MAC [7] and RTS/CTS MAC [8] with MSDU set to zero.	
48.	Max (<i>Asynch</i>)	The maximum delay can be essentially infinite depending on the number of nodes and type of data mix being sent. In a simulation using DCF with 10 nodes - 4 sending voice packets, 2 sending video packets and 4 sending data packets, the average delays were 20msec for voice packets, approximately 1.1 seconds for video and infinite for the data packets [9]. In another model [10], the average media access delay for 4 stations in ad hoc mode using DCF and sending a mixture of data, video and voice, was approximately 3.5 seconds. Both sources [9] and [10] also provide data for the case where EDCF is used instead of DCF. Source [7] also shows EDCF with and without Contention-Free Bursts.	
49.	Min (<i>Isoch</i>)	N/A	
50.	Max (<i>Isoch</i>)	N/A	

Line #	Characteristic	Performance	Committee Observations
51.	Jitter:		
52.	Jitter (<i>Asynch</i>)	Typical Max 700us [13]	
53.	Jitter (<i>Isoch</i>)	N/A	
54.	Delay (Round Trip):		
55.	Min (<i>Asynch</i>)	Twice One-way delay. See 802.11 Timing Sheet, Table B-1, Figure B-1 for CSMA/CA MAC [7] and RTS/CTS MAC [8] with MSDU set to zero.	
56.	Max (<i>Asynch</i>)	The maximum delay can be essentially infinite depending on the number of nodes and type of data mix being sent.	
57.	Min (<i>Isoch</i>)	N/A	
58.	Max (<i>Isoch</i>)	N/A	
59.	Error Rates:		
60.	Bit Error Rate	Unknown	
61.	Packet Error Rate	Vendor specific but typical: 11Mbps = -84dbm @8% PER 2Mbps = -90dbm @8% PER	
62.	Security:		
63.	Admission	Open system authentication when no authentication is required. Shared key authentication verification of an authenticating wireless client with knowledge of a shared secret when authentication is required.	
64.	Authentication	When using Basic Service Set (BSS), a shared key is used between stations & the AP. When using Extended Service Set (ESS), all APs use the same shared key. There is no key management, shared key must be entered manually to stations and APs. [See notes 11 & 12].	
65.	Encryption	Supports both 64 and 128-bit WEP encryption.	
66.	Integration:		
67.	Convergence Layers	It supports Ethernet but not 1394	
68.	Component Availability	Yes	
69.	Mobility:		
70.	Roaming	Wireless clients are mobile and can roam within coverage area of an AP. Multiple access points are allowed on a single subnet. When a client is passed from one AP to another, the original session is lost.	
71.	Multipath Handling	Suffers from Multipath. Result is a reduction in transmission rate. This is mitigated using antenna diversity at access point (typically two or more antennas).	
72.	Power Consumption		
73.	Idle State		No response provided.
74.	Sleep Mode		No response provided.
75.	Active Max		No response provided.
76.	Active Min		No response provided.
77.	Other factors that affect power consumption		No response provided.

Notes and References:		
IEEE 802.11 Extensions:		
IEEE 802.11e	QoS	
IEEE 802.11h	European extensions	
IEEE 802.11i	Security	
IEEE 802.11j	Japan frequency bands	
IEEE 802.11k	Radio resource measurement	
IEEE 802.11f	Inter-Access Point protocols	
IEEE 802.11n	Throughput >100Mbps at MAC SAP	
IEEE 802.11r	Fast Roaming between BSSIDs	
IEEE 802.11s	Extended Services Set (ESS Mesh)	
[1]	WME	
[2]	802.11e	
[3]	There are other technologies emerging that are not part of the standard to address the issue. Revolution routers use specially developed adaptive mechanism of querying (polling).	
[4]	Measurement Methodology: Vasan/Shankar Empirical Method	
<u>Configuration</u>	<u>Nodes</u>	<u>Measurement Environment</u>
Ad hoc	2	low ambient noise
Infrastructure	AP+3	low ambient noise
Infrastructure	AP+6	low ambient noise
[5]	Measurement methodology: Vasan/Shankar Empirical Method	
<u>Configuration</u>	<u>Nodes</u>	<u>Measurement Environment</u>
Ad hoc	2	low ambient noise/minimum obstructions
Infrastructure	AP+3	low ambient noise/minimum obstructions

Notes	and References:		
[6]		An Empirical Characterization of Instantaneous Throughput in 802.11b WLANs Arunchandar Vasan and A. Udaya Shankar Department of Computer Science University of Maryland, College Park, MD 20742	
[7]		For 1500 byte packet as calculated from Table B-1 (below), HR-11 - CSMA/CA MAC, from Second IEEE International Symposium on Network Computing and Applications April 16 - 18, 2003 Cambridge, Massachusetts	
		Theoretical Maximum Throughput of IEEE 802.11 and its Applications	
		Jangeun Jun, Pushkin Peddabachagari, Mihail Sichitiu	
		Department of Electrical and Computer Engineering	
		North Carolina State University	
[8]		Calculated from Table B-1 802.11 Timing Sheet (see below), HR-11 - RTS/CTS MAC, from Second IEEE International Symposium on Network Computing and Applications April 16 - 18, 2003 Cambridge, Massachusetts	
		Theoretical Maximum Throughput of IEEE 802.11 and its Applications	
		Jangeun Jun, Pushkin Peddabachagari, Mihail Sichitiu	
		Department of Electrical and Computer Engineering	
		North Carolina State University	
[9]		MERL: MITSUBISHI ELECTRIC RESEARCH LABORATORY	
		http://www.merl.com	
		EVALUATION OF EDCF MECHANISM For QoS IN IEEE WIRELESS NETWORKS	
		Daqing Gu and Jinyun Zhang	
		TR-2003-51 May 2003	
[10]		IEEE 802.11e Contention-Based Channel Access (EDCF) Performance Evaluation	
		Sunghyun Choi	
		Multimedia and Wireless Networking Laboratory (MWNL)	

Notes and References:		
		School of Electrical Engineering
		Seoul National University, Seoul, Korea
		schoi@snu.ac.kr
		Sai Shankar N, Stefan Mangold, Javier del Prado
		Philips Research USA
		Wireless Communications and Networking
		Briarcliff Manor, New York, USA
		{javier.delprado,sai.shankar,stefan.mangold}@philips.com
[11]		802.11i is addressing weaknesses in the built-in security features. The WiFi Alliance recommends WPA (a subset of 802.11i) for improved security services.
[12]		802.11b does not support key management. 802.11i supports 802.1x key management.
[13]		Characterization of MPEG-4 Traffic over IEEE 802.11b Wireless LANs
		Praveen Ikkurthy and Miguel A. Labrador
		Department of Computer Science and Engineering
		University of South Florida, Tampa, FL 33620, U.S.A
		{ikkurthy,labrador}@csee.usf.edu

Figure B-1: CSMA/CA and RTS/CTS Cycles

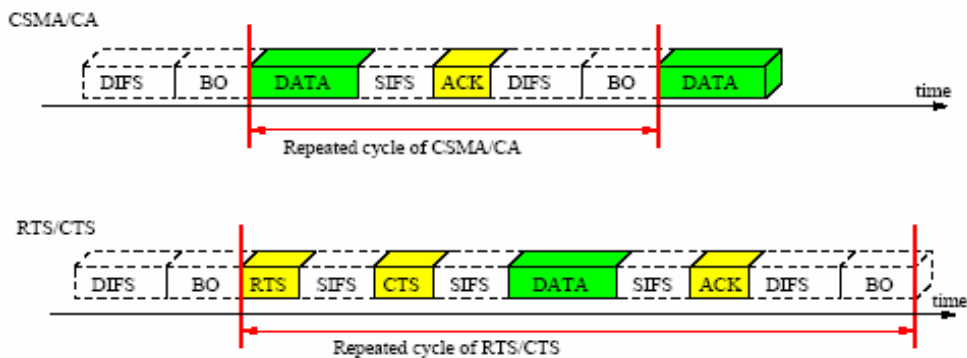


Table B-1: 802.11 Timing Sheet – Timing for One-Way and Two-Way Delay Calculations

Modulation	Mode	T _{DIFS}	T _{SIFS}	T _{BO}	T _{RTS}	T _{CTS}	T _{ACK}	T _{DATA}	T _{DATA} MSDU 1500 bytes	1-way	1-Way MSDU set to Zero	2- Way	2-Way MSDU set to Zero
CSMA/CA													
FHSS-1	802.11	128	28	375	N/A	N/A	240	$128+33/32*8*(34+MSDU)/1$	12784	13555	771	27109	1542
FHSS-2	802.11	128	28	375	N/A	N/A	240	$128+33/32*8*(34+MSDU)/2$	6456	7227	771	14454	1542
DSSS-1	802.11	50	10	310	N/A	N/A	304	$192+8*(34+MSDU)/1$	12464	13138	674	26276	1348
DSSS-2	802.11	50	10	310	N/A	N/A	304	$192+8*(34+MSDU)/2$	6328	7002	674	14004	1348
HR-5.5	802.11b	50	10	310	N/A	N/A	304	$192+8*(34+MSDU)/5.5$	2423	3097	674	6195	1348
HR-11	802.11b	50	10	310	N/A	N/A	304	$192+8*(34+MSDU)/11$	1308	1982	674	3963	1348
OFDM-6	802.11a/g	34	9	67.5	N/A	N/A	44	$20+4*((16+6+8*(34+MSDU))/24)$	2069	2224	155	4447	309
OFDM-9	802.11a/g	34	9	67.5	N/A	N/A							
OFDM-12	802.11a/g	34	9	67.5	N/A	N/A	32	$20+4*((16+6+8*(34+MSDU))/38)$	1314	1457	143	2913	285
OFDM-18	802.11a/g	34	9	67.5	N/A	N/A							
OFDM-24	802.11a/g	34	9	67.5	N/A	N/A	28	$20+4*((16+6+8*(34+MSDU))/96)$	532	671	139	1342	277
OFDM-36	802.11a/g	34	9	67.5	N/A	N/A							
OFDM-48	802.11a/g	34	9	67.5	N/A	N/A							
OFDM-54	802.11a/g	34	9	67.5	N/A	N/A	24	$20+4*((16+6+8*(34+MSDU))/216)$	248	382	135	764	269
RTS/CTS													
FHSS-1	802.11	128	84	375	288	240	240	$128+33/32*8*(34+MSDU)/1$	12784	14307	1523	28613	3046
FHSS-2	802.11	128	84	375	288	240	240	$128+33/32*8*(34+MSDU)/2$	6456	7979	1523	15958	3046
DSSS-1	802.11	50	30	310	352	304	304	$192+8*(34+MSDU)/1$	12464	13874	1410	27748	2820
DSSS-2	802.11	50	30	310	352	304	304	$192+8*(34+MSDU)/2$	6328	7738	1410	15476	2820
HR-5.5	802.11b	50	30	310	352	304	304	$192+8*(34+MSDU)/5.5$	2423	3833	1410	7667	2820
HR-11	802.11b	50	30	310	352	304	304	$192+8*(34+MSDU)/11$	1308	2718	1410	5435	2820
OFDM-6	802.11a/g	34	27	67.5	52	44	44	$20+4*((16+6+8*(34+MSDU))/24)$	2069	2392	323	4783	645
OFDM-9	802.11a/g	34	27										
OFDM-12	802.11a/g	34	27	67.5	36	32	32	$20+4*((16+6+8*(34+MSDU))/38)$	1314	1597	283	3193	565
OFDM-18	802.11a/g	34	27										
OFDM-24	802.11a/g	34	27	67.5	28	28	28	$20+4*((16+6+8*(34+MSDU))/96)$	532	799	267	1598	533
OFDM-36	802.11a/g	34	27										
OFDM-48	802.11a/g	34	27										
OFDM-54	802.11a/g	34	27	67.5	24	24	24	$20+4*((16+6+8*(34+MSDU))/216)$	248	502	255	1004	509

NOTES:

1. All numbers are microseconds
2. CSMA/CA 1-way=DIFS+DATA+SIFS+ACK
3. CSMA/CA round trip=2*1way (air time ignored, approx. 1 microsecond/1000 ft.)
4. RTS/CTS 1-way=DIFS+RTS+SIFS+CTS+SIFS+DATA+SIFS+ACK
5. RTS/CTS round trip=2*1way (air time ignored, approx. 1 microsecond/1000 ft.)

Annex C. IEEE 802.11a/b/g

Line #	Characteristic	Performance	Committee Observations
1.	Frequency Band:		
2.	USA	2.412-2.462GHz (802.11g), 5.180-5805GHz (802.11a)	
3.	Europe	2.412-2.472GHz (802.11g), 5.180-5700GHz (802.11a) France (2457-2473GHz) and Spain (2457-2462GHz) only partial coverage of the spec	
4.	Japan	2.412-2.484GHz(802.11g), in 2.48GHz only CCK modulation is allowed. 5170-5230GHz	
5.	# of RF Channels:		
6.	USA	11 (802.11b/g in 2.4G band), 23 (802.11a in 5G band)	
7.	Europe	13 (802.11b/g in 2.4G band), 19 (802.11a in 5G band)	
8.	Japan	14 (802.11b/g in 2.4G band), 4 (802.11a in 5G band)	channels 10 and 5 are narrower in Japan; different requirements for indoors and outside
9.	Bandwidth per RF Channel:		
10.	USA	20Mhz	
11.	Europe	20Mhz	
12.	Japan	20Mhz	
13.	Transmit Power (EIRP):		
14.	USA	1W (2.4G band), 200mW (5.15-5.25), 400mW (5.25-5.35), 800mW (5.4-5.8)	
15.	Europe	100mW (2.4G band), 200mW (5.15-5.35), 1W (5.4-5.7)	
16.	Japan	10mW/MHz	
17.	Transmit Power (Dynamic):		
18.	USA	yes	
19.	Europe	yes - mandatory	exact requirements vary within Europe
20.	Japan	yes	
21.	QoS:		
22.	Deterministic	Yes, with WSM implemented. Statistical with WME	
23.	Priority Classes	4 (Best Effort, Video, Audio, Background)	
24.	Parameterized	yes	
25.	Isochronous	no	
26.	# of Isochronous Channels	N/A	

Line #	Characteristic	Performance	Committee Observations
27.	Network Structure:		
28.	Topologies Enabled	Ad-hoc, Infrastructure, AP-AP Repeater and Bridge Mode, Direct Link Protocol	see Atheros for consistent terms and more detailed breakdown / Mesh topology eventually (11s recently formed), some proprietary mesh nets now
29.	# of addressable nodes	up to 2048 maximum	Determined by implementation drives which items wander out of range
30.	Hidden node handling	Use RTS/CTS to overcome hidden node. Higher throughput modes when not using RTS/CTS with risk of hidden node.	
31.	Network Loading:		
32.	Network sensitivity when nodes are added	No sensitivity. Shared access and collision avoidance used to share the network.	
33.	Network sensitivity to increased loading on existing nodes	Collision avoidance based on Carrier Sense and Energy Detection. Contention Windows in exponential up to Cwmax.	
34.	RF Channel Selection Method	Manual. Dynamic not specified by spec. And implementation dependent. DFS (dynamic freq. selection) are defined in 802.11h for the 5GHz band (802.11a) and can be used for the 2.4G as well but not standardized.	
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	802.11 provides a variety of methods of coexistence with other WLANs, including network discovery: active and passive scanning, transmit power control, link quality and RSSI information (implementation dependent), a channel plan that minimizes overlap with existing WLANs, dynamic channel selection.	
37.	Inherent tolerance to in-band interference	The PHY coding diminishes the effect of narrow-band interferers. Equalization in the receiver also reduces the effect of these on the received SNR. 802.11h defines radio measurements modes that help radio management, and channel selection as needed by application level.	
38.	Out of Band Noise Floor	< -50dBc in 802.11b, < -47dBc for 802.11a/g	
39.	Speed:		
40.	Throughput (<i>Asynch</i>)	> 30Mbps in standard 802.11g when working in 54Mbps, 35 Mbps when using Packet Bursting (WME) techniques, >40Mbps when using proprietary vendor defined aggregation techniques	
41.	Throughput (<i>Isoch</i>)	N/A	
42.	Network Join Time	typical 40mSec with dynamic association	
43.	Link Rate	54Mbps	
44.	Range:		
45.	Coverage Area	up to 100-160ft	measured lab results with a simulated office environment

Line #	Characteristic	Performance	Committee Observations
46.	Delay (1 Way):		
47.	Min (<i>Asynch</i>)	89uSec (not including data, assume Cwmin=0, at highest modulation rate)	Different assumptions than in individual responses for 802.11a and 802.11g
48.	Max (<i>Asynch</i>)	up to 800uSec assume lowest rate - 802.11b lowest rates (no CTS/RTS etc.), highest security mode	Different assumptions than in individual responses for 802.11a and 802.11g
49.	Min (<i>Isoch</i>)	N/A	
50.	Max (<i>Isoch</i>)	N/A	
51.	Jitter:		
52.	Jitter (<i>Asynch</i>)	collision dependent	
53.	Jitter (<i>Isoch</i>)	N/A	
54.	Delay (Round Trip):		
55.	Min (<i>Asynch</i>)		No response provided.
56.	Max (<i>Asynch</i>)		No response provided.
57.	Min (<i>Isoch</i>)	N/A	
58.	Max (<i>Isoch</i>)	N/A	
59.	Error Rates:		
60.	Bit Error Rate	< 1E-5 with 1024 octet payload for sensitivity compliance. Real life application gets much better BER with no interferences (<1E-6)	
61.	Packet Error Rate	<8% in 1024 octet for sensitivity compliance in 802.11b rate, <10% in 1024 octet for sensitivity compliance in 802.11a/g rates. Typical application <<1%. per packet and block. Ack method and retransmissions result in PER << 8-10%.	
62.	Security:		
63.	Admission	open, shared key	
64.	Authentication	open, 802.1x with EAP-TLS, PEAP, and more	
65.	Encryption	WEP, CCMP, TKIP	
66.	Integration:		
67.	Convergence Layers	802 LLC in standard RFC1042	
68.	Component Availability	yes	some features not implemented though (e.g. PCF which no one can get to work right)
69.	Mobility:		
70.	Roaming	application dependent, 802.11r will define standard method	determined by 11f now (for roaming services)
71.	Multipath Handling	Equalizer, Diversity	
72.	Power Consumption		
73.	Idle State		No response provided.
74.	Sleep Mode		No response provided.

Line #	Characteristic	Performance	Committee Observations
75.	Active Max		No response provided.
76.	Active Min		No response provided.
77.	Other factors that affect power consumption		No response provided.

Annex D. IEEE 802.11a

Line #	Characteristic	Performance	Committee Observations
1.	Frequency Band:		
2.	USA	5.15-5.25GHz, 5.25-5.35GHz, 5.470-5.725GHz, 5.725-5.825/5.850GHz	
3.	Europe	Germany, UK: 5.15-5.25GHz, 5.25-5.35GHz, 5.470-5.725GHz; France: 5.15-5.25GHz, 5.25-5.35GHz	
4.	Japan	4.90-5.00GHz (open in 2005), 5.03-5.09GHz, 5.15-5.25GHz	
5.	# of RF Channels:		
6.	USA	24ch. total: 5.15-5.25GHz<4ch>, 5.25-5.35GHz<4ch>, 5.470-5.725GHz<11ch>, 5.725-5.825/5.850GHz<4/5ch>	23 and 1 under NPRM
7.	Europe	19ch total: Germany, UK: 5.15-5.25GHz<4ch>, 5.25-5.35GHz<4ch>, 5.470-5.725GHz<11ch>	
8.	Japan	4ch total: 4.90-5.00GHz (open in 2005) <3ch>, 5.03-5.09GHz<3ch>, 5.15-5.25GHz<4ch>	4 now, 7 expected
9.	Bandwidth per RF Channel:		
10.	USA	20MHz	
11.	Europe	20MHz	
12.	Japan	20MHz	
13.	Transmit Power (EIRP):		
14.	USA	5.15-5.25GHz<200mW>, 5.25-5.35GHz<1W>, 5.470-5.725GHz<1W>, 5.725-5.825/5.850GHz<4W>	
15.	Europe	Germany, UK: 5.15-5.25GHz<200mW>, 5.25-5.35GHz<200mW>, 5.470-5.725GHz<1W>	
16.	Japan	4.90-5.00GHz (open in 2005)<TBD>, 5.03-5.09GHz<200mW>, 5.15-5.25GHz<200mW>	
17.	Transmit Power (Dynamic):		
18.	USA	Yes (1-8 levels)	can lower the power levels based on the application needs, 8 levels defined in the spec but application sets actual values of those levels (vendor specific), FCC requires 6Db down step
19.	Europe	Yes (1-8 levels)	
20.	Japan	Yes (1-8 levels)	
21.	QoS:		
22.	Deterministic	Basic 802.11a (no); 11e WME (EDCF-no), 11e WSM (HCF-nearly)	

Line #	Characteristic	Performance	Committee Observations
23.	Priority Classes	Basic 802.11a (no); 11e WME (EDCF: 8 user priority levels identical to 802.1D priority tags mapped into 4 priority access categories - voice, video, control, best effort), 11e WSM (WME plus HCF)	
24.	Parameterized	Yes	can adjust various parameters and can use HCF - but can't reserve bandwidth / 11a is no, 11e with WME is no, 11e WSM (which also includes HCF) optional & limited bandwidth reservation (can request, no guarantee but can adjust parameters to lock out others)
25.	Isochronous	No	no time stamping, no clock
26.	# of Isochronous Channels	N/A	
27.	Network Structure:		
28.	Topologies Enabled	Ad-Hoc, Infrastructure, AP-AP Repeater (non-standard) and Bridging (non-standard), Direct Link Protocol (11e)	
29.	# of addressable nodes	2007 maximum stations associated with AP at any given time (Association ID range)	typically more like 64 or maybe 128 association ID's (MAC numbers) an access point has
30.	Hidden node handling	RTS/CTS mechanism with CSMA/CA - RTS clears air near transmitter, CTS clears air near receiver. Reduces effective throughput.	
31.	Network Loading:		
32.	Network sensitivity when nodes are added	Access mechanism is CSMA/CA. Minimal impact on network as nodes are added if they do not create traffic, but impact increases as nodes create traffic.	some impact for polling, more sensitive to actual traffic than nodes
33.	Network sensitivity to increased loading on existing nodes	Access mechanism is CSMA/CA with exponential back off after failed contention. Network access slows as nodes increase traffic.	
34.	RF Channel Selection Method	Basic 802.11a uses manual channel selection. Most vendor implementations include dynamic selection as option. 11h requires dynamic frequency selection (DFS) to avoid radars.	
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	Fundamental CSMA/CA & RTS/CTS access mechanism based on collision avoidance allows possibility of multiple LANs. Dynamic frequency selection (11h) can be used to detect presence of other signals (radar, HiperLAN, ...) and find a clear channel. Tx power can be adjusted.	typically use set up a planned channel selection scheme to avoid interference of channel crowding
37.	Inherent tolerance to in-band interference		No response provided.
38.	Out of Band Noise Floor	Tx spectrum mask: <-40dB @30MHz freq. Offset (-52dB typical); sideband suppression: <50dBc typical	
39.	Speed:		

Line #	Characteristic	Performance	Committee Observations
40.	Throughput (<i>Asynch</i>)	Basic 802.11a: 22Mbps TCP/IP throughput on 54Mbps link; WME (packet bursting, etc.): 35Mbps; proprietary schemes using content compression yield up to 45Mbps; proprietary schemes using channel bonding yield up to 90Mbps; 11n will increase to 100Mbps+ on single channel, 200Mbps+ with channel bonding. Throughput is a marketing specs-manship game among the vendors.	packet bursting can increase, can send multiple packets before dealing with ACK/NACK results of previous packets, can also send multiple packets without even waiting on ACKs (used to keep the bus till done sending packets), and can further increase with compression of input files
41.	Throughput (<i>Isoch</i>)	N/A	
42.	Network Join Time	Typically <40ms.	
43.	Link Rate	54Mbps maximum on single 20MHz channel.	
44.	Range:		
45.	Coverage Area	Depends on environment and required bit rate. Basic 802.11a: Typical office/home can realize up to 150ft. or more through several walls with bit rate decreasing to 6Mbps. Proprietary schemes can extend range to several 100 ft., but at bit rates below 6Mbps. No standard measurement environment and procedure exist.	
46.	Delay (1 Way):		
47.	Min (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Min (54Mbps)=382usec, MSDU=1500 byte; =135usec, MSDU=0; no loading assumed	Same as 802.11g
48.	Max (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Max (6Mbps)=2392usec, MSDU=1500 byte; =323usec, MSDU=0; RTS/CTS assumed; no loading assumed	Same as 802.11g
49.	Min (<i>Isoch</i>)	N/A	
50.	Max (<i>Isoch</i>)	N/A	
51.	Jitter:		
52.	Jitter (<i>Asynch</i>)	Statistical, depends on network loading & collision statistics. Proprietary mechanisms exist to reduce/eliminate.	
53.	Jitter (<i>Isoch</i>)	N/A	
54.	Delay (Round Trip):		
55.	Min (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Min (54Mbps)=764usec, MSDU=1500 byte; =269usec MSDU=0 byte; no loading assumed	Same as 802.11g
56.	Max (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Max (6Mbps)=4783usec, MSDU=1500 byte; =645usec, MSDU=0; RTS/CTS assumed; no loading assumed	Same as 802.11g
57.	Min (<i>Isoch</i>)	N/A	
58.	Max (<i>Isoch</i>)	N/A	
59.	Error Rates:		
60.	Bit Error Rate		No response provided.

Line #	Characteristic	Performance	Committee Observations
61.	Packet Error Rate	<10% PER at a PSDU length of 1000 bytes for rate-dependent input sensitivity levels: OFDM 6Mbps, -82dBm min.; OFDM 54Mbps, -65dBm min.	
62.	Security:		
63.	Admission	Open, Shared Key	
64.	Authentication	Open, Shared Key with challenge text (4 shared keys), 1x (EAP, LEAP)	LEAP is proprietary
65.	Encryption	WEP(RC4, symmetric keys of 40, 104 or 128-bit length), WPA (TKIP), WPA2 (AES, 128-bit key) ->11i	
66.	Integration:		
67.	Convergence Layers	802.2 LLC	
68.	Component Availability	Yes, multiple vendors	
69.	Mobility:		
70.	Roaming	Not part of basic 802.11 standard. Vendor-specific Layer 2 roaming now. 11r standard in development.	
71.	Multipath Handling	Basic 11a: OFDM equalization, antenna switched diversity; 11n: MIMO	
72.	Power Consumption		
73.	Idle State		No response provided.
74.	Sleep Mode		No response provided.
75.	Active Max		No response provided.
76.	Active Min		No response provided.
77.	Other factors that affect power consumption		No response provided.

Annex E. IEEE 802.11g

Line #	Characteristic	Performance	Committee Observations
1.	Frequency Band:		This is a very crowded band, esp. as more new and extended uses of WiFi are being developed.
2.	USA	2.4-2.4835GHz	
3.	Europe	2.4-2.4835GHz	
4.	Japan	2.4-2.497GHz	
5.	# of RF Channels:		Few channels available so network saturates pretty quickly for a video stream.
6.	USA	3	
7.	Europe	3	
8.	Japan	3	
9.	Bandwidth per RF Channel:		
10.	USA	20MHz	
11.	Europe	20MHz	
12.	Japan	20MHz	
13.	Transmit Power (EIRP):		
14.	USA	1W	
15.	Europe	100mW	
16.	Japan	10mW/Hz (200mW)	
17.	Transmit Power (Dynamic):		same as 802.11a
18.	USA	Yes (1-8 levels)	
19.	Europe	Yes (1-8 levels)	
20.	Japan	Yes (1-8 levels)	
21.	QoS:		same as 802.11a
22.	Deterministic	Basic 802.11g (no); 11e WME (EDCF-no), 11e WSM (HCF-nearly)	
23.	Priority Classes	Basic 802.11g (no); 11e WME (EDCF: 8 user priority levels identical to 802.1D priority tags mapped into 4 priority access categories - voice, video, control, best effort), 11e WSM (WME plus HCF)	
24.	Parameterized	Yes	
25.	Isochronous	No	
26.	# of Isochronous Channels	N/A	
27.	Network Structure:		
28.	Topologies Enabled		same as 802.11a

Line #	Characteristic	Performance	Committee Observations
29.	# of addressable nodes	2007 maximum stations associated with AP at any given time (Association ID range)	same as 802.11a
30.	Hidden node handling	RTS/CTS mechanism with CSMA/CA - RTS clears air near transmitter, CTS clears air near receiver. Reduces effective throughput.	same as 802.11a
31.	Network Loading:		
32.	Network sensitivity when nodes are added	Access mechanism is CSMA/CA. Minimal impact on network as nodes are added if they do not create traffic, but impact increases as nodes create traffic.	same as 802.11a
33.	Network sensitivity to increased loading on existing nodes	Access mechanism is CSMA/CA with exponential back off after failed contention. Network access slows as nodes increase traffic.	
34.	RF Channel Selection Method	Basic 802.11g uses manual channel selection. Most vendor implementations include dynamic selection as option.	same as 802.11a can also be done in the application
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	Fundamental CSMA/CA & RTS/CTS access mechanism based on collision avoidance allows possibility of multiple LANs. Dynamic frequency selection (11h) can be used to detect presence of other signals (Bluetooth, ...) and find a clear channel. Tx power can be adjusted.	slightly different than 802.11a: optional dynamic selection also will drop down to "b" level when necessary
37.	Inherent tolerance to in-band interference		No response provided.
38.	Out of Band Noise Floor	Tx spectrum mask: <-40dBm @30MHz freq. Offset: -52dBm typical. Sideband suppression: <50dBc typical	same as 802.11a
39.	Speed:		
40.	Throughput (Asynch)	Basic 802.11g: 22Mbps TCP/IP throughput on 54Mbps link; WME (packet bursting, etc.): 35Mbps; proprietary schemes using content compression yield up to 45Mbps; proprietary schemes using channel bonding yield up to 90Mbps; 11n will increase to 100Mbps+ on single channel, 200Mbps+ with channel bonding. Throughput is a marketing specsmanship game among the vendors.	several modes and variables available (burst, limits on retries, etc.)
41.	Throughput (Isoch)	N/A	
42.	Network Join Time	typically <40ms.	same as 802.11a
43.	Link Rate	54Mbps maximum on single 20MHz channel.	same as 802.11a
44.	Range:		
45.	Coverage Area	Depends on environment and required bit rate. Basic 802.11g: Typical office/home can realize up to 150ft. or more through several walls with bit rate decreasing to 6Mbps. Proprietary schemes can extend range to several 100 ft., but at bit rates below 6Mbps. No standard measurement environment and procedure exist.	goes through walls better than 802.11a in some cases
46.	Delay (1 Way):		

Line #	Characteristic	Performance	Committee Observations
47.	Min (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Min (54Mbps)=382usec, MSDU=1500 byte; =135usec, MSDU=0; no loading assumed	same as 802.11a
48.	Max (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Max (6Mbps)=2392usec, MSDU=1500 byte; =323usec, MSDU=0; RTS/CTS assumed; no loading assumed	same as 802.11a
49.	Min (<i>Isoch</i>)	N/A	
50.	Max (<i>Isoch</i>)	N/A	
51.	Jitter:		
52.	Jitter (<i>Asynch</i>)	Statistical, depends on network loading & collision statistics. Proprietary mechanisms exist to reduce/eliminate.	same as 802.11a
53.	Jitter (<i>Isoch</i>)	N/A	
54.	Delay (Round Trip):		
55.	Min (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Min (54Mbps)=764usec, MSDU=1500 byte; =269usec MSDU=0 byte; no loading assumed	same as 802.11a
56.	Max (<i>Asynch</i>)	See 802.11 timing table spreadsheet. Max (6Mbps)=4783usec, MSDU=1500 byte; =645usec, MSDU=0; RTS/CTS assumed; no loading assumed	same as 802.11a
57.	Min (<i>Isoch</i>)	N/A	
58.	Max (<i>Isoch</i>)	N/A	
59.	Error Rates:		
60.	Bit Error Rate	E-25	
61.	Packet Error Rate	<10% PER at a PSDU length of 1000 bytes for rate-dependent input sensitivity levels: OFDM 6Mbps,-82dBm min.; OFDM 54Mbps, -65dBm min.	
62.	Security:		same as 802.11a
63.	Admission	Open, Shared Key	
64.	Authentication	Open, Shared Key with challenge text (4 shared keys), 11x (EAP, LEAP)	
65.	Encryption	WEP(RC4, symmetric keys of 40, 104 or 128-bit length), WPA (TKIP), WPA2 (AES, 128-bit key) ->11i	
66.	Integration:		
67.	Convergence Layers	802.2 LLC	same as 802.11a
68.	Component Availability	Yes, multiple vendors	same as 802.11a ("a" vendors also supply "g", but some "g" vendors don't supply "a")
69.	Mobility:		
70.	Roaming	Not part of basic 802.11 standard. Vendor-specific Layer 2 roaming now. 11r standard in development.	same as 802.11a
71.	Multipath Handling		same as 802.11a
72.	Power Consumption		
73.	Idle State		No response provided.

Line #	Characteristic	Performance	Committee Observations
74.	Sleep Mode		No response provided.
75.	Active Max		No response provided.
76.	Active Min		No response provided.
77.	Other factors that affect power consumption		No response provided.

Annex F. IEEE 802.15.1

Line#	Characteristic	Performance	Committee Observations
1.	Frequency Band:		
2.	USA	2.4-2.4853 GHz (FCC 47CFR15.247)	
3.	Europe	2.4-2.4835 GHz (ETSI ETS 300-328)	
4.	Japan	2.4-2.4835 GHz (ARIB STD-T66)	
5.	# of RF Channels:		
6.	USA	79	
7.	Europe	79	
8.	Japan	79	
9.	Bandwidth per RF Channel:		
10.	USA	1 MHz	
11.	Europe	1 MHz	
12.	Japan	1 MHz	
13.	Transmit Power (EIRP):		
14.	USA	100 mW	
15.	Europe	100 mW	
16.	Japan	100 mW	
17.	Transmit Power (Dynamic):		
18.	USA	Yes--device dependent Class 1 = Max 100mW (20dBm), Min 1mW (0dBm); Class 2 = Max 2.5mW (4dBm), Min 0.25mW (-6dBm); Class 3 = Max 1mW (0 dBm), recommend <-30dBm Min	
19.	Europe	Yes--device dependent Class 1 = Max 100mW (20dBm), Min 1mW (0dBm); Class 2 = Max 2.5mW (4dBm), Min 0.25mW (-6dBm); Class 3 = Max 1mW (0 dBm), recommend <-30dBm Min	
20.	Japan	Yes--device dependent Class 1 = Max 100mW (20dBm), Min 1mW (0dBm); Class 2 = Max 2.5mW (4dBm), Min 0.25mW (-6dBm); Class 3 = Max 1mW (0 dBm), recommend <-30dBm Min	
21.	QoS:		
22.	Deterministic	yes	
23.	Priority Classes	No	
24.	Parameterized	Yes	

Line#	Characteristic	Performance	Committee Observations
25.	Isochronous	No, uses synchronous operation	
26.	# of Isochronous Channels	0	
27.	Network Structure:		
28.	Topologies Enabled	Piconet: Ad-Hoc, Star	
29.	# of addressable nodes	7	
30.	Hidden node handling	Uses TDMA protocol so there are not any collisions due to hidden nodes.	
31.	Network Loading:		
32.	Network sensitivity when nodes are added	Network is stable with up to the maximum number of nodes.	
33.	Network sensitivity to increased loading on existing nodes	The piconet Master will only allocate up to the available time in the network, so the network is very stable under heavy loading, up to 100% of the available throughput. The Master is able to exercise channel access control to prevent loads in excess of the available throughput.	
34.	RF Channel Selection Method	Pseudo-random hopping sequence	
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	coexistence with WLANs via transmit power control	
37.	Inherent tolerance to in-band interference	frequency hopping to minimize the effects of in-band interference	
38.	Out of Band Noise Floor	Interfering Signal Frequency (Interfering Signal Power Level) 30 MHz - 2000MHz (-10dBm) 2000MHz - 2399MHz (-27dBm) 2484MHz - 3000MHz (-27dBm) 3000MHz - 12.75GHz (-10dBm)	
39.	Speed:		
40.	Throughput (<i>Asynch</i>)	Nominal data rate is 1Mbit/sec. Payload throughput is very dependent on type of services selected. Using an ALC link with DH5 packets (which have no FEC and have up to 2712 payload bits) a maximum MAC throughput of about 700 Kbps is achieved. The topology is a single Master with up to 7 slaves forming a independent piconet.	
41.	Throughput (<i>Isoch</i>)	Synchronous, rather than Isochronous services are available. With an SCO link 64 Kbps is achieved for 3 simultaneous links, with limited retransmission	
42.	Network Join Time	< 3sec for 99%	
43.	Link Rate	1Mbps	
44.	Range:		
45.	Coverage Area	10meters	
46.	Delay (1 Way):		
47.	Min (<i>Asynch</i>)	0 μ s	

Line#	Characteristic	Performance	Committee Observations
48.	Max (<i>Asynch</i>)	1250µs with three SCO links scheduled between transmit and response	
49.	Min (<i>Isoch</i>)	N/A	
50.	Max (<i>Isoch</i>)	N/A	
51.	Jitter:		
52.	Jitter (<i>Asynch</i>)	Worst case values drift = 250ppm and jitter = 10µs	
53.	Jitter (<i>Isoch</i>)	N/A	
54.	Delay (Round Trip):		
55.	Min (<i>Asynch</i>)	625µs	
56.	Max (<i>Asynch</i>)	1875µs with three SCO links scheduled between transmit and response	
57.	Min (<i>Isoch</i>)	N/A	
58.	Max (<i>Isoch</i>)	N/A	
59.	Error Rates:		
60.	Bit Error Rate	The BER shall be ≤ 0.1% at input power -20dBm, indoor, nominal temperature. Packet size and retransmission do not apply to BER. FEC will improve BER if used, dependent on the nature of the interference.	
61.	Packet Error Rate	PER is not specified	
62.	Security:		Provides security measures at the application and link layers.
63.	Admission	Master determines admission and can use authentication methods to make decision..	
64.	Authentication	Provided by link layer. Authentication routines specified to be included in all devices.	
65.	Encryption	128 bit. Uses linear feedback shift registers (LFSRs) whose output is combined by a simple finite state machine (called the summation combiner) with 16 states. The output of this state machine is the key stream sequence, or, during initialization phase, the randomized initial start value. The algorithm uses an encryption key, a 48-bit Bluetooth address, the master clock bits CLK26-1, and up to a 128-bit RAND value. Encryption routines specified to be included in all devices.	
66.	Integration:		
67.	Convergence Layers	802 LLC in standard, Bluetooth protocol layers, as defined in Bluetooth SIG Specification v1.2	
68.	Component Availability	Yes	
69.	Mobility:		
70.	Roaming	N/A	
71.	Multipath Handling	Frequency hopping	
72.	Power Consumption		

Line#	Characteristic	Performance	Committee Observations
73.	Idle State	Idle and Listen states are different. Idle = 47 μ A Listen = 0.5 mA	(standby, not connected mode) (listening for a new connection)
74.	Sleep Mode	0.55 mA	(parked: connected and listening every 1.28 seconds)
75.	Active Max	45 mA	(transferring data 720 Kbps)
76.	Active Min	5 mA	(active connection but no data transfer)
77.	Other factors that affect power consumption		No response provided.

Annex G. IEEE 802.15.1a (Bluetooth)

Line#	Characteristic	Performance	Committee Observations
1.	Frequency Band:		
2.	USA	2.4-2.4853 GHz (FCC 47CFR15.247)	
3.	Europe	2.4-2.4835 GHz (ETSI ETS 300-328)	
4.	Japan	2.4-2.4835 GHz (ARIB STD-T66)	
5.	# of RF Channels:		
6.	USA	79	
7.	Europe	79	
8.	Japan	79	
9.	Bandwidth per RF Channel:		
10.	USA	1 MHz	
11.	Europe	1 MHz	
12.	Japan	1 MHz	
13.	Transmit Power (EIRP):		
14.	USA	100 mW	
15.	Europe	100 mW	
16.	Japan	100 mW	
17.	Transmit Power (Dynamic):		
18.	USA	Yes--device dependent Class 1 = Max 100mW (20dBm), Min 1mW (0dBm); Class 2 = Max 2.5mW (4dBm), Min 0.25mW (-6dBm); Class 3 = Max 1mW (0 dBm), recommend <-30dBm Min	
19.	Europe	Yes--device dependent Class 1 = Max 100mW (20dBm), Min 1mW (0dBm); Class 2 = Max 2.5mW (4dBm), Min 0.25mW (-6dBm); Class 3 = Max 1mW (0 dBm), recommend <-30dBm Min	
20.	Japan	Yes--device dependent Class 1 = Max 100mW (20dBm), Min 1mW (0dBm); Class 2 = Max 2.5mW (4dBm), Min 0.25mW (-6dBm); Class 3 = Max 1mW (0 dBm), recommend <-30dBm Min	
21.	QoS:		
22.	Deterministic	yes	
23.	Priority Classes	No	
24.	Parameterized	Yes	

Line#	Characteristic	Performance	Committee Observations
25.	Isochronous	No, uses synchronous operation	
26.	# of Isochronous Channels	0	
27.	Network Structure:		
28.	Topologies Enabled	Piconet: ad-hoc, star	
29.	# of addressable nodes	7	
30.	Hidden node handling	Uses TDMA protocol so there are not any collisions due to hidden nodes.	
31.	Network Loading:		
32.	Network sensitivity when nodes are added	Network is stable with up to the maximum number of nodes.	
33.	Network sensitivity to increased loading on existing nodes	The piconet Master will only allocate up to the available time in the network, so the network is very stable under heavy loading, up to 100% of the available throughput. The Master is able to exercise channel access control to prevent loads in excess of the available throughput.	
34.	RF Channel Selection Method	Pseudo-random hopping sequence, with adaptive frequency hopping to avoid occupied channels.	
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	coexistence with WLANs via transmit power control and adaptive frequency hopping channel selection.	
37.	Inherent tolerance to in-band interference	uses frequency hopping to minimize the effects of in-band interference.	
38.	Out of Band Noise Floor	Interfering Signal Frequency [Interfering Signal Power Level] 30MHz - 2000MHz (-10dBm) 2000MHz - 2399MHz (-27dBm) 2484MHz - 3000MHz (-27dBm) 3000MHz - 12.75GHz (-10dBm)	
39.	Speed:		
40.	Throughput (<i>Asynch</i>)	Nominal data rate is 1Mbit/sec. Payload throughput is very dependent on type of services selected. Using an ALC link with DH5 packets (which have no FEC and have up to 2712 payload bits) a maximum MAC throughput of about 700Kbps is achieved. The topology is a single Master with up to 7 slaves forming a independent piconet.	
41.	Throughput (<i>Isoch</i>)	Synchronous, rather than Isochronous services are available. With an eSCO link 64 Kbps is achieved for 3 simultaneous links, with limited retransmission	
42.	Network Join Time	< 3 sec for 99%	
43.	Link Rate	1Mb/s	
44.	Range:		
45.	Coverage Area	10meters	
46.	Delay (1 Way):		
47.	Min (<i>Asynch</i>)	0 μ s	

Line#	Characteristic	Performance	Committee Observations
48.	Max (<i>Asynch</i>)	1250 μ s with three SCO links scheduled between transmit and response	
49.	Min (<i>Isoch</i>)	N/A	
50.	Max (<i>Isoch</i>)	N/A	
51.	Jitter:		
52.	Jitter (<i>Asynch</i>)	Worst case values drift=250ppm and jitter=10 μ s	
53.	Jitter (<i>Isoch</i>)	N/A	
54.	Delay (Round Trip):		
55.	Min (<i>Asynch</i>)	625 μ s	
56.	Max (<i>Asynch</i>)	1875 μ s with three SCO links scheduled between transmit and response	
57.	Min (<i>Isoch</i>)	N/A	
58.	Max (<i>Isoch</i>)	N/A	
59.	Error Rates:		
60.	Bit Error Rate	The BER shall be $\leq 0.1\%$ at input power -20dBm, indoor, nominal temperature. Packet size and retransmission do not apply to BER. FEC will improve BER if used, dependent on the nature of the interference.	
61.	Packet Error Rate	Packet Error Rate not specified	
62.	Security:		Provides security measures at the application and link layers.
63.	Admission	Master determines admission and can use authentication methods to make decision.	
64.	Authentication	Provided by link layer. Authentication routines specified to be included in all devices.	
65.	Encryption	128 bit. Uses linear feedback shift registers (LFSRs) whose output is combined by a simple finite state machine (called the summation combiner) with 16 states. The output of this state machine is the key stream sequence, or, during initialization phase, the randomized initial start value. The algorithm uses an encryption key, a 48-bit Bluetooth address, the master clock bits CLK26-1, and up to a 128-bit RAND value. Encryption routines specified to be included in all devices.	
66.	Integration:		
67.	Convergence Layers	802 LLC in standard, Bluetooth protocol layers, as defined in Bluetooth SIG Specification v1.2	
68.	Component Availability	Yes	
69.	Mobility:		
70.	Roaming	N/A	
71.	Multipath Handling	Frequency hopping, with adaptive frequency hopping algorithm to avoid interference.	
72.	Power Consumption		
73.	Idle State		No response provided.

Line#	Characteristic	Performance	Committee Observations
74.	Sleep Mode		No response provided.
75.	Active Max		No response provided.
76.	Active Min		No response provided.
77.	Other factors that affect power consumption		No response provided.

Annex H. IEEE 802.15.3

Line#	Characteristic	Performance	Committee Observations
1.	Frequency Band:		
2.	USA	2.4-2.4853GHz (FCC 47CFR15.247)	
3.	Europe	2.4-2.4835GHz (ETSI ETS 300-328)	
4.	Japan	2.4-2.4835GHz (ARIB STD-T66)	
5.	# of RF Channels:		
6.	USA	4, with all 4 useable without reduction in throughput, spacing is at least 16 MHz.	
7.	Europe	4, with all 4 useable without reduction in throughput, spacing is at least 16 MHz.	
8.	Japan	4, with all 4 useable without reduction in throughput, spacing is at least 16 MHz.	
9.	Bandwidth per RF Channel:		
10.	USA	15MHz	
11.	Europe	15MHz	
12.	Japan	15MHz	
13.	Transmit Power (EIRP):		
14.	USA	4W (1 W with up to 6dBi antenna)	
15.	Europe	100mW	
16.	Japan	10mW/MHz (< 27dBm for 15MHz bandwidth)	
17.	Transmit Power (Dynamic):		
18.	USA	Yes (device dependent but must be able to reduce power to 0dBm or below in 3dB steps)	
19.	Europe	Yes (device dependent but must be able to reduce power to 0dBm or below in 3dB steps)	
20.	Japan	Yes (device dependent but must be able to reduce power to 0dBm or below in 3dB steps)	
21.	QoS:		
22.	Deterministic	yes	
23.	Priority Classes	Yes, 8 priority classes	
24.	Parameterized	Yes (Application sets the parameters.)	
25.	Isochronous	Yes	
26.	# of Isochronous Channels	253	
27.	Network Structure:		

Line#	Characteristic	Performance	Committee Observations
28.	Topologies Enabled	Peer-to-Peer, Ad Hoc, Managed Peer-to-Peer, Mesh (data exchange only, per 802.15.5), Infrastructure mode (Star), Bridged Peer-to-Peer (data exchange only) Shadow mode approximates a controller-less network. Devices copy all of the PNC activity and store all the network parameters (Shadow) so that any shadowing device can instantly take over as the new PNC should the old one drop out.	
29.	# of addressable nodes	236	
30.	Hidden node handling	Uses TDMA protocol so there are not any collisions due to hidden nodes.	
31.	Network Loading:		
32.	Network sensitivity when nodes are added	Network is stable with up to the maximum number of nodes. Network becomes “busy” instead of overloaded.	
33.	Network sensitivity to increased loading on existing nodes	The piconet controller (PNC) will only allocate up to the available time in the network, so the network is very stable under heavy loading, up to 100% of the available throughput. The PNC is able to exercise channel access control to prevent loads in excess of the available throughput.	
34.	RF Channel Selection Method	Dynamic, the piconet controller (PNC) is able to change the channel based on interference and performance considerations.	
35.	Interference (emission and tolerance):		
36.	Co-existence with other WLANs	802.15.3 provides a variety of methods of coexistence with other WLANs, including passive scanning, transmit power control, child and neighbor piconet capability, the ability to request channel quality information, link quality and RSSI information, a channel plan that minimizes overlap with existing WLANs, dynamic channel selection, and a lower impact transmit spectral mask.	
37.	Inherent tolerance to in-band interference	The PHY coding diminishes the effect of narrow-band interferers. Equalization in the receiver also reduces the effect of these on the received SNR. In addition, the piconet can schedule around periodic interferers to avoid times when they are broadcasting.	
38.	Out of Band Noise Floor	< -50dBc, < -42dBm/MHz in US	
39.	Speed:		
40.	Throughput (<i>Asynch</i>)	> 42Mb/s (no FEC is defined in 802.15.3) with BER < 10E-6, PER < 1%, frame size 2044 octets)	
41.	Throughput (<i>Isoch</i>)	> 42Mb/s (no FEC is defined in 802.15.3) with BER < 10E-6, PER < 1%, frame size 2044 octets)	
42.	Network Join Time	< 0.5second	
43.	Link Rate	55Mb/s	
44.	Range:		

Line#	Characteristic	Performance	Committee Observations																								
45.	Coverage Area	<p>Assumption: +14 dBm transmitter output power, + 2 dBi gain antenna at each end</p> <table border="1"> <thead> <tr> <th>Rate</th> <th>Range (meters)</th> </tr> </thead> <tbody> <tr> <td>11</td> <td>206</td> </tr> <tr> <td>22</td> <td>125</td> </tr> <tr> <td>33</td> <td>117</td> </tr> <tr> <td>44</td> <td>94</td> </tr> <tr> <td>55</td> <td>75</td> </tr> </tbody> </table> <p>Assumption: +15 dBm transmitter output power, 0 dBi gain antenna at each end</p> <table border="1"> <thead> <tr> <th>Rate</th> <th>Range (meters)</th> </tr> </thead> <tbody> <tr> <td>11</td> <td>167</td> </tr> <tr> <td>22</td> <td>102</td> </tr> <tr> <td>33</td> <td>95</td> </tr> <tr> <td>44</td> <td>76</td> </tr> <tr> <td>55</td> <td>61</td> </tr> </tbody> </table> <p>These are all based on the 802.11 channel model and assume 4 dB implementation loss, and 7 dB noise figure with a signal bandwidth of 11 MHz.</p>	Rate	Range (meters)	11	206	22	125	33	117	44	94	55	75	Rate	Range (meters)	11	167	22	102	33	95	44	76	55	61	PER not provided
Rate	Range (meters)																										
11	206																										
22	125																										
33	117																										
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Rate	Range (meters)																										
11	167																										
22	102																										
33	95																										
44	76																										
55	61																										
46.	Delay (1 Way):																										
47.	Min (<i>Asynch</i>)	< 30us																									
48.	Max (<i>Asynch</i>)	< 65ms under low asynchronous loading.																									
49.	Min (<i>Isoch</i>)	<30 us																									
50.	Max (<i>Isoch</i>)	< 65ms (assumes maximum superframe duration), low latency devices can request additional allocations to reduce this to < 10ms																									
51.	Jitter:																										
52.	Jitter (<i>Asynch</i>)	< 65 ms																									
53.	Jitter (<i>Isoch</i>)	< 4 ms																									
54.	Delay (Round Trip):																										
55.	Min (<i>Asynch</i>)	< 1 ms																									
56.	Max (<i>Asynch</i>)	< 65 ms																									
57.	Min (<i>Isoch</i>)	< 1ms																									
58.	Max (<i>Isoch</i>)	< 65ms																									
59.	Error Rates:																										
60.	Bit Error Rate	< 1E-5 with 1024 octet payload for sensitivity compliance. < 1E-6 in typical application, measured with 2044 octet payload, no MAC level FEC. Tx power is +14dBm, 55Mb/s																									
61.	Packet Error Rate	< 8% for sensitivity compliance, < 1% in application, without MAC level FEC. Link rate is 55Mb/s, +14dBm Tx power.																									
62.	Security:		See Note [1]																								
63.	Admission	Piconet controller determines admission and can use authentication methods to make decision.																									

Line#	Characteristic	Performance	Committee Observations
64.	Authentication	Access Control list, Mutual Authentication, Key Establishment and Authorization are provided by upper layers.	
65.	Encryption	128 bit AES CCM	
66.	Integration:		
67.	Convergence Layers	802 LLC in Standard, 1394 PAL, IPv6 in development	
68.	Component Availability	Development systems available, ASICs 3Q05	
69.	Mobility:		
70.	Roaming	Handled by upper layers and with mesh topology	(implementation specific)
71.	Multipath Handling	Mitigated with equalizers, typical capability is > 50ns rms delay spread. MIMO is applicable.	
72.	Power Consumption	These estimates include the “radio system,” which consists of the MAC (including CPU and memory), base band (modem), and RF section (including A/D and D/A converters). The CPU is assumed to be the ARM9 running at 200 MHz. It also assumes that the digital sections (MAC and baseband) are implemented in an ASIC using 130 nm process. The supply voltage is assumed to be 1.6 V for the digital section and 3.3 V for the RF section. The memory is also assumed to have a certain level of leakage (i.e., 10%) that consumes some power	
73.	Idle State	5.9 mW In IDLE state, the device is assumed to operate in power-saving mode and wake up every 16 th superframe (e.g., light sleep) to listen to the beacon. The device goes back to sleep if no data is pending for it; otherwise, it enters the ACTIVE state. While the device is asleep, powers to the baseband and RF section are turned off, and the CPU is running in the low-power standby mode.	
74.	Sleep Mode	2.8 mW In SLEEP mode, the device is assumed to operate in power-saving mode and wake up every 64 th superframe (e.g., deep sleep) to listen to the beacon. The device goes back to sleep if no data is pending for it; otherwise, it enters the ACTIVE state.	
75.	Active Max	792 mW In ACTIVE mode, the maximum power consumption is calculated assuming the device is transmitting and receiving, 45% of duty cycle each (typical for streaming scenarios), and is transmitting at an output power level of +18 dBm.	
76.	Active Min	165 mW In ACTIVE mode, the minimum power consumption is calculated assuming the device is receiving most of the time (e.g., 99%) during its assigned time slot in a typical streaming scenario and goes to standby mode for the rest of the superframe duration. When transmitting, the +0 dBm output power was assumed.	

Line#	Characteristic	Performance	Committee Observations
77.	Other factors that affect power consumption	<p>The low power states were designed to meet the target applications requirements of battery powered devices. As long as the application of power save is implemented to preserve QoS needs of the application, there should be no impact on customer performance. For example, there is no “unpark” time or re-sync time because of the TDMA scheduling mechanisms. Additionally, this TDMA based system allows QoS, security, and noise mitigation to all be deterministically preserved in the low power modes through reservations with the PNC.</p> <p>The system can be designed to "wake on preamble" or wake based on elapsed time. Unlike CDMA protocols, the system can be woken up much closer to its scheduled time to receive. When the system is in asleep, it can shut down everything except the clock running at a low frequency. The PNC or the Device can establish the Power Save policy depending on the application requirements. Several different power management modes are designed in. Groups of devices can have the same power save parameters so that they power save and be available to each other as a synchronized group.</p> <p>Additionally, advanced on-chip power management can be employed to further reduce power consumption, such as clock gating, clock frequency control, threshold voltage control, and power domain management.</p>	

Notes	and References:		
[1]	Line 62 - Security	<p>The following security services are provided for:</p> <ol style="list-style-type: none"> 1- Key Transport – The key originator in a relationship can update the symmetric keys that are used, and the devices in the relationship can also request new keys if the detect that the encryption keys have changed. 2- Data Encryption: This service provides privacy for the data that are being transmitted in the piconet. If the piconet group key is used, every DEV in the piconet will be able to read and understand the data. The data can also be protected using a key that is only shared between two devices. 3- Data Integrity – Frames that require data integrity use an Integrity Code field that is part of the frame format to protect the data from modification and to verify the source of the data. 4- Beacon Integrity Protection: The information in the beacon is not encrypted because it is used by devices that are searching for piconets to join. The information in the beacon is protected by an Integrity Code Field to protect the information from modification and to verify that it was sent by the PNC. 5- Freshness Protection – Every beacon sent by a PNC includes a time token that is used by the encryption algorithm as one of the inputs used to create the nonce. The time token is included in the beacon regardless of the security mode. This enables peer-to-peer security in a piconet that is operating without PNC security. 6- Command Integrity Protection – Like the beacon, most commands sent in a piconet operating in security mode, include an Integrity Code Field to verify that the command has not been modified to verify the identity of the source of the command. 	

