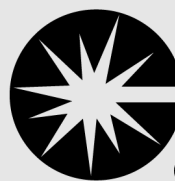


CEA Technical Paper

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**

Document ID: 123456789

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 Not critical	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								

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	US Frequency Bands	Max Throughput (Payload Bit Rate)	QoS Characteristics	Robustness	Delay Characteristics	Security Characteristics	Network Topologies	General Comments
(Common Name, Standard Number)	Channelization Number of Close Proximity Networks (User Channels)	Range Characteristics (Coverage Area, Roaming)	(Prioritized, Parameterized, Asynchronous**, Isochronous, Deterministic**)	(Error Susceptibility***, Coexistence, Tolerance to Interference, Adding Nodes)	(1-Way, Round Trip, Jitter)	(Admission, Authentication, Encryption)	Number of Nodes Supported Modes of Operation	(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	

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)
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> ▪ 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	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 value.	
Bluetooth Like IEEE 802.15.1a, except LLC is different						Additional features	LLC different	

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)
IEEE 802.15.3	2.4GHz, 4 15MHz RF Channels	<u>Throughput:</u> 42 Mbps <u>Range:</u> 61m (at 55 Mbps) 102m (22 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. <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> Can schedule around periodic interferers. <u>Loading:</u> Piconet controller schedules transmissions (allocates network bandwidth), so network is stable under heavy loading.	<u>1-Way (max):</u> Asynch: <65ms (typical loading) Isoch: <10ms (typical loading, and by requesting channel allocation) <u>Round Trip (max):</u> Isoch: <65ms (typical loading) <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> Shadow controller 1394 PAL	Capabilities fall generally in between WIFI and Bluetooth (802.11 and 802.15.1) Standard was developed for multi-media applications.

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)

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)
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> ▪ 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> ▪ 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	

1

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.