I Foro WiFi de RedIRIS 802.11n

Telecommunications Technological Centre of Catalonia

Christos Verikoukis, PhD
Senior Research Associate

Barcelona 22/4/08

CTTC facts and figures

CTTC (www.cttc.es)

- Non profit private organization. Mainly founded by the Catalan government
- Staff: 15 Administrative and direction, 21 PhD researchers, 17 Telecom Engineers, 2 Post doc, 7 Associate researchers, 14 PhD students
- Research Areas: Radio Communications, Access Technologies, IP Technologies, Optical Networking and Communications Subsystems

ACCESS TECHNOLOGIES AREA (www.cttc.es/wiki/access)

- Staff: 5 PhD researchers, 1 Telecom Engineer
- Publications (1Q 2003 – 1Q 2008): 16 in journals, 5 book chapters, 60 in conferences
- Participation in projects
  - 16 European (IST, ICT,MEDEA+, CELTIC and ESA): PHYDIAS,WIP, NEWCOM++, ACE/ACE2, NEWCOM, WINNER, WIDENS, LOOP, WISQUAS, PLANETS, MARQUIS, MIMOWA, ESA MIMOSAT, ESoA, DYNAMO-COST295
  - 2 National (CICYT): Perseo, ULTRA-MED
  - 5 Industrial Contracts
  - 1 Internal (strategic)
- Graduate and undergraduate training
  - 7 PhD Students
  - 6 Master Theses (20 completed Theses)

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Access Technologies

Research Lines

- PHY-MAC Resource Allocation algorithms and protocols in Wireless Networks (ad-hoc, sensor, relay, infrastructure).
  - Distributed, multi-radio and cooperative MAC protocols.
  - Cross-Layer power allocation mechanisms with throughput, delay and QoS constraints.
  - Cross-Layer multiuser scheduling for SISO/MIMO systems.
  - Radio Resource Management schemes based on Cross-Layer for a distributed queuing MAC protocol.
  - MAC-level misbehavior mechanisms for cooperative systems.
- Resource Allocation for Beyond 3G Systems.
  - Adaptive multi-carrier schemes and Beyond 3G systems.
  - Spectrum allocation and cognitive radio.
- Multi-terminal Communications
  - Cooperative communications; capacity limits, and applications for mesh and sensor networks.
  - Cross-layer integration and network coding.

Technologies Considered

- WiMax (IEEE802.16)
- WiFi (IEEE802.11x)
- WSN (IEEE802.15.4)

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Outline

- Introduction
- 802.11n at a glance
- History of TGn
- 802.11n Characteristics
- 802.11n Certification
- 802.11n Electricity Issues

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Introduction

Future Network

“Pervasive Collaborative Computing”

Faster and
More Pervasive

More
Secure

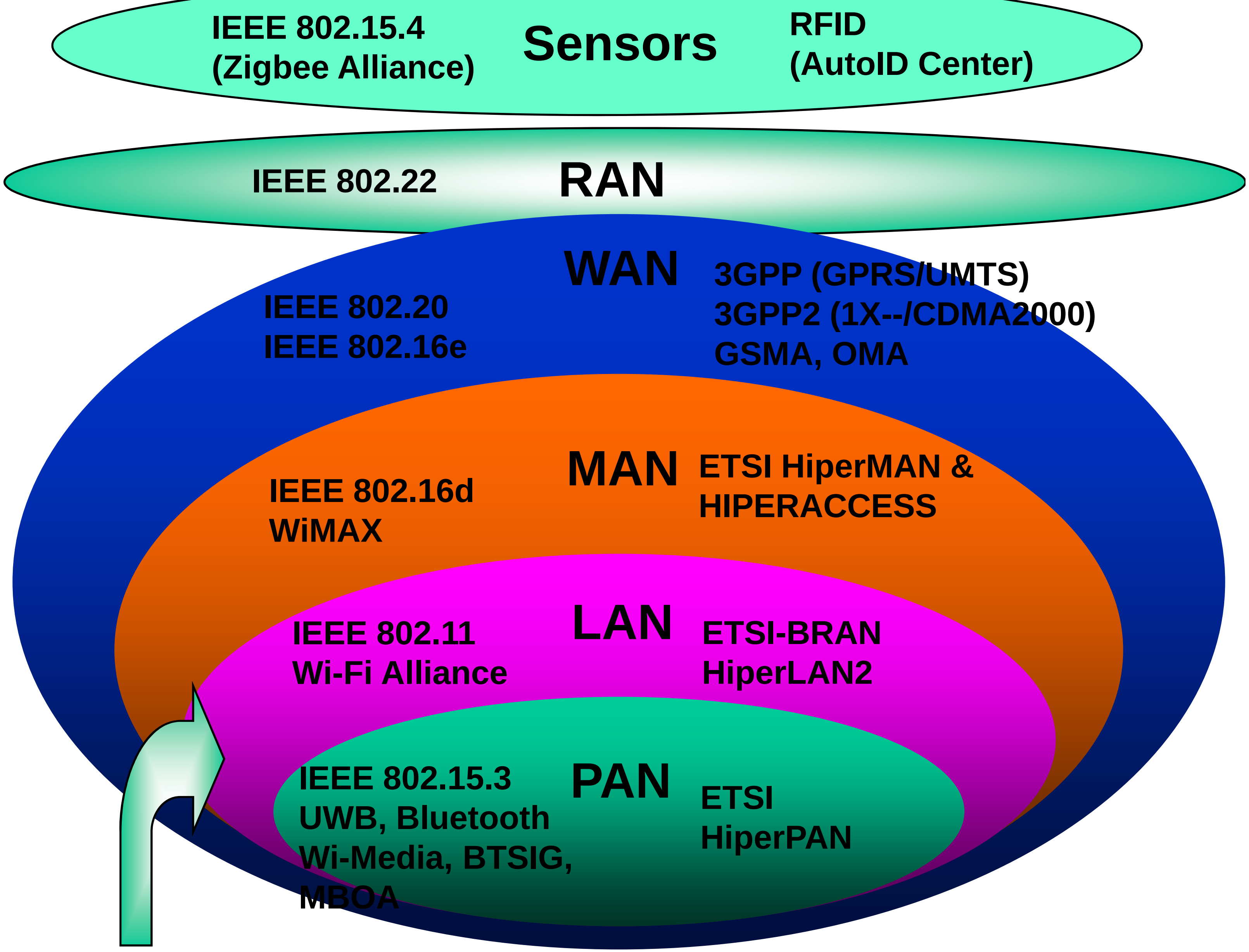
More
Deployable
and Manageable

Ease
At Home

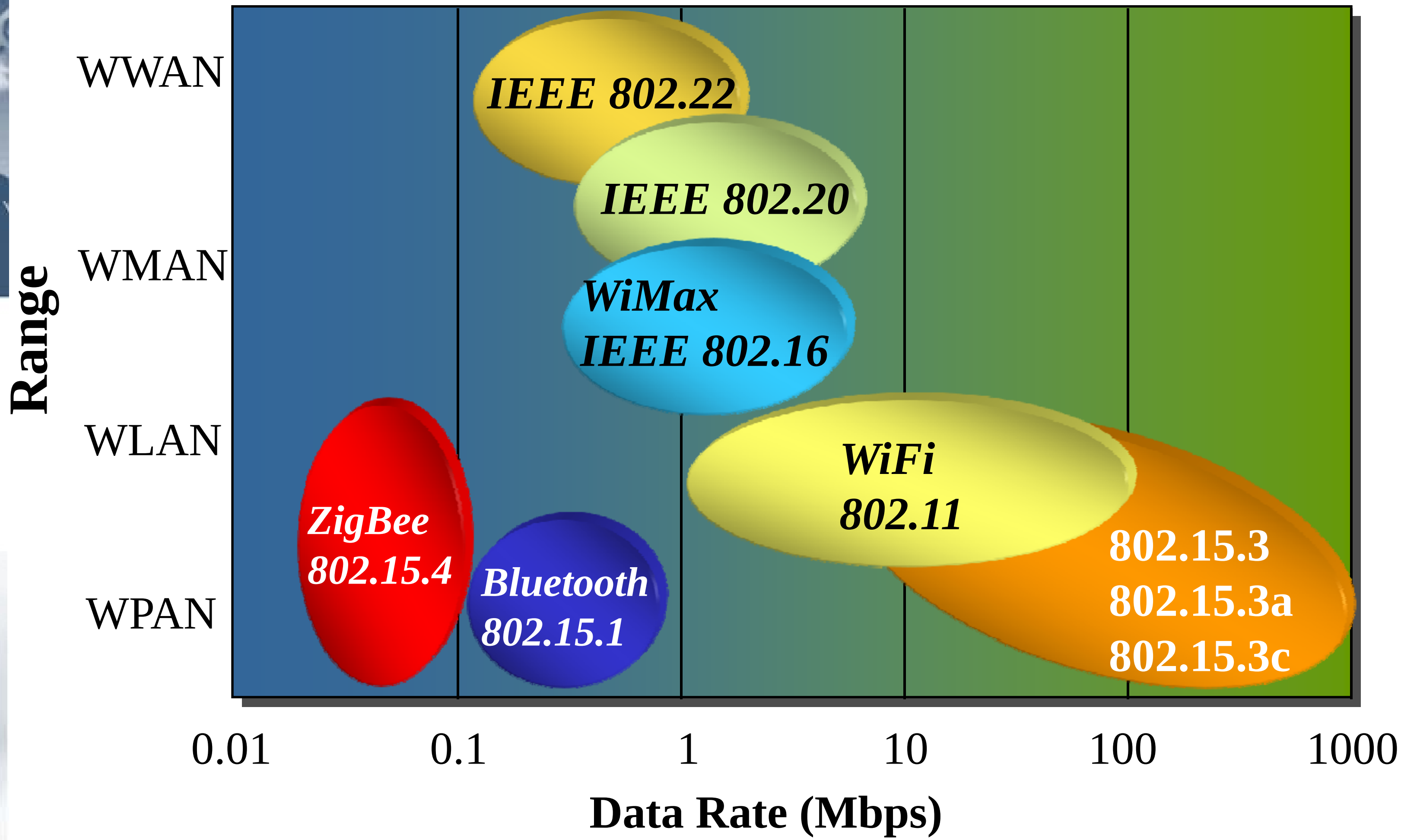
CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

Centre Tecnològic de Telecomunicacions de Catalunya

Wireless Standards



The Wireless Space



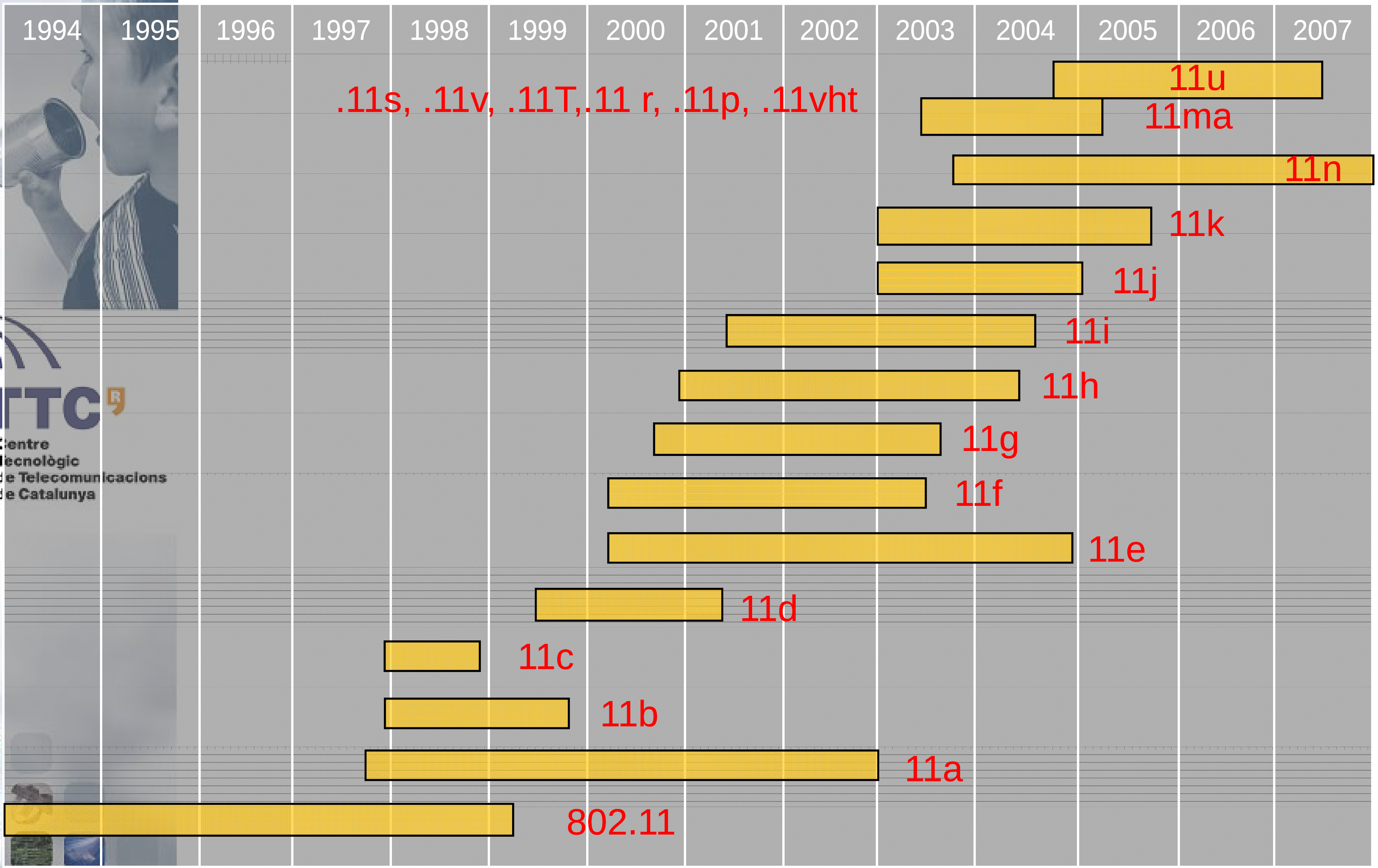
CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

What end-users want

- Range: reliable wireless networking.
- High fidelity: good Quality of Service for high quality audio and video.
- Throughput!

- WLAN in the:
  - home
  - small business
  - enterprise
  - education
  - healthcare
  - universities
  - hospitality
  - ……

802.11x Working Groups



CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

802.11 Standards

W-LAN Standard	802.11b	802.11a	802.11g
Band	2.4 GHz	5 GHz	2.4 GHz
Max Speed	11 Mbps	54 Mbps	54 Mbps
Market Acceptance	Fully commercially available	Market acceptance still unknown	Fully commercially available
Strengths	•Wide acceptance •Interoperability •Low installation costs •Fully supported by many hardware and software vendors	•Uses 5 GHz band (less congestions) •Increased transmission speed	•Increased transmission speed •Backwards-Compatibility with 802.11b
Weaknesses	•Poor security •Relatively low speed •High concentration & congestion in the 2.4 GHz band	•Does not offer backwards compatibility (namely with 802.11b) •Relatively poor security	•Uses crowded 2.4 GHz band

CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

802.11n at a glance

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

IEEE 802.11n WG

- Develop next generation Wi-Fi capable of much higher throughputs, with a maximum throughput of at least 100Mbps, as measured at the MAC data service access point.

- Modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC) to support high throughput.

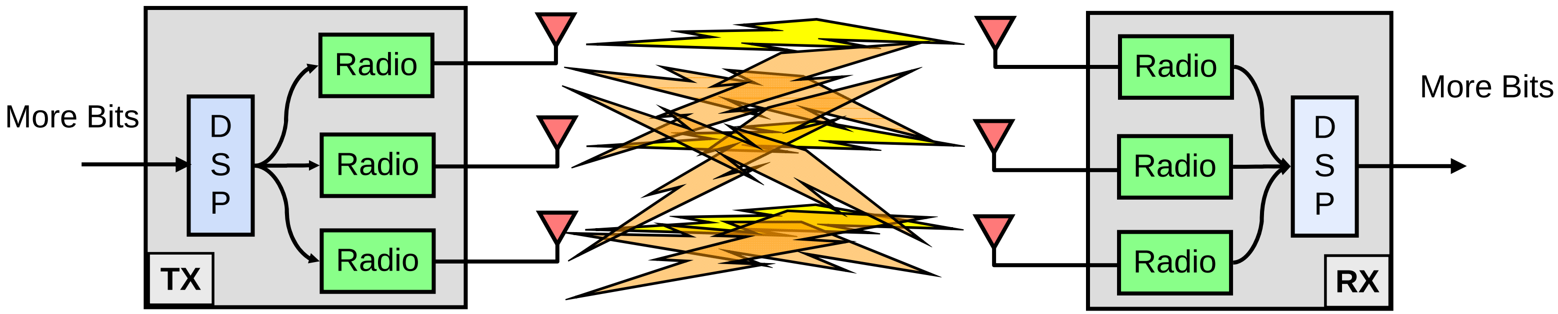
- Evaluation metrics: throughput, range, network capacity, (peak and average power consumption), spectral flexibility, backward compatibility, and coexistence (3 channel models).

New components in 802.11n

- **PHY Enhancements**, applicable to both 2.4GHz and 5GHz
  - Multiple Input Multiple Output (MIMO) Radio Technology With Spatial Multiplexing.
  - High throughput PHY – 40 MHz channels – Two adjacent 20 MHz channels are combined to create a single 40 MHz channel.
- **MAC Enhancements**
  - Two MAC aggregation methods are supported to efficiently pack smaller packets into a single MPDU.
  - Block Acknowledgement – A performance optimization in which an IEEE 802.11 ACK frame need not follow every unicast frame and combined acknowledgements may be sent at a later point in time.
  - Reduce Interframe Spacing.

MIMO

Multiple independent data streams are sent between the transmit and receive antennas to deliver more bits in the specified bandwidth.



- Cross-paths between antennas are automatically decoded by the receiver, assuming sufficient "richness" in the propagation environment.

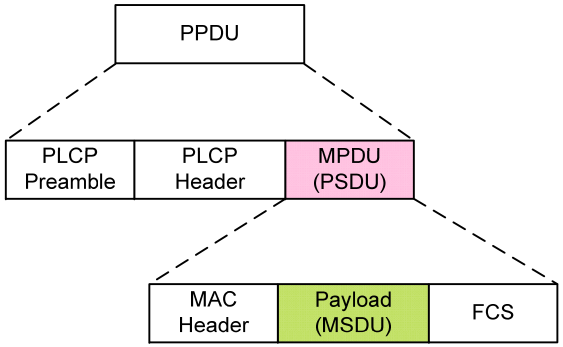
CTTC

Centre Tecnològic de Telecomunicacions de Catalunya

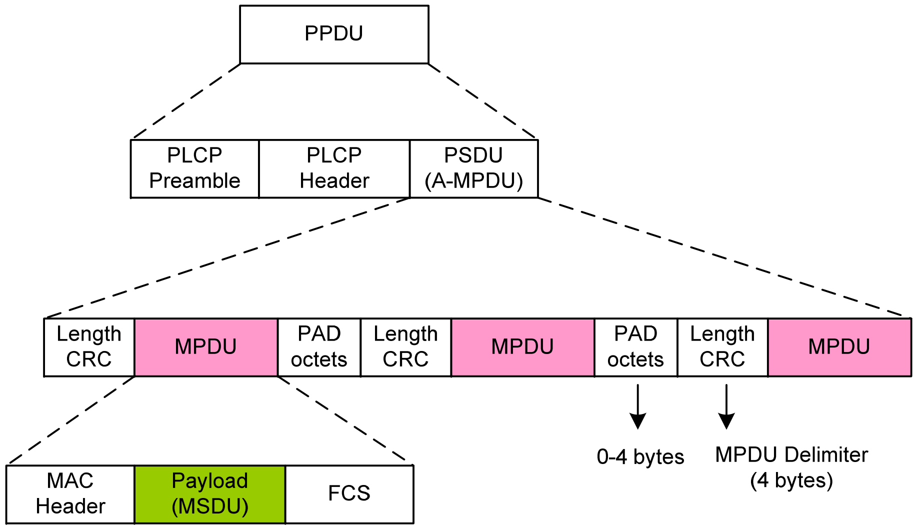
Aggregated MPDU (A-MPDU)

- Multiple MDPUs (MAC data frames) are joined in a single PSDU.
  - Multiple frames under the same PHY header
  - All MPDUs must have the same receiver.
  - Errors in one MPDU do not imply the loss of all MPDUs (robust delimiting by the CRC field).

Legacy 802.11



802.11n A-MPDU



CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Benefits from 802.11n

- **Increased capacity.**
  - 802.11n enables increased data rates, improving the usable data capacity of a cell.
- **Improved range.**
- **More uniform ‘reliable’ coverage.**
  - Reduce the effect of multipath nulls.
- **Lower Network Costs.**
  - Fewer APs, lower installation costs, possibly fewer LAN edge switch ports, and fewer outdoor APs to cover campus areas between buildings.

CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

History of TGn

History of TGn

- HTSG formed – First meeting (Sep. 2002 Monterey).
- TGn formed – First meeting (Sep. 2003 Singapore).
- Began call for proposals (May 2004 Garden Grove).

- 32 First round presentations (Sep. 2004 Berlin).
- Discussion of these 32 proposals. The majority of time was spent discussing the 4 complete proposals: **MITMOT, TGnSync, WWiSE, and Qualcomm.** (Nov. 2004, S.Antonio).
  - MITMOT 47.4%
  - TGnSync 73.7%
  - WWiSE 64.7%
  - Qualcomm 56.8%

  The threshold for further consideration was 25%.

- Three complete proposals MITMOT, TGnSync (After 14 hours of Qualcom and Mitsubishi merged with TGn Sync) and WWiSE were presented presentations and discussion a down select vote was held that resulted in the elimination of the MITMOT proposal (January 2005, California).

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

TGSync vs. WWISE

Features	TGn Sync	WWISE
Bandwidth	(M) 20MHz mode (M) 40MHz, whenever regulatory domain permits this extension	(M) 20 MHz mode (O) 40 MHz mode
MIMO-OFDM-SDM	(M) 2 spatial streams @ 20MHz mode	(M) 2 spatial streams @ 20MHz mode
Higher code rate (R)	(M) R= ½, 2/3, ¾, 7/8	(M) R= ½, 2/3, ¾, 5/6
Regular coding scheme	(M) Convolutional code	(M) Convolutional code
Advanced Coding scheme	(O) LDPC	(O) LDPC
Space Time Block Code	(N)	(O)

History of TGn

- Down selected to one proposal (Mar 2005 Atlanta) –first confirm vote failed.
- Confirmation vote #2 failed - reset to 3 proposals -left the May 2005 meeting with a serious deadlock. (Cairns, Queensland Australia).
- <u>3 proposal groups agreed to a joint proposal activity (Jul 2005 San Francisco)</u>
- Joint Proposal accepted by vote of 184/0/4, editor instructed to create draft (Jan 2006 Waikoloa).
- Baseline specification converted into **Draft 1.0 (335p)**. Letter ballot issued (LB84) March 2006 (Denver) and closed on April 2006 (failed to get 75% of the votes).
- Draft 1.0 Comment resolution begins (May 2006 Jacksonville).
  - To expedite the process the comments were grouped into 8 topic areas: **PHY, MAC, PSMP, Coexistence, Editorial, Coexistence Assurance, Frame Format & General**. Using this method it was possible to conduct several discussions in parallel.
- Approved 6711 editorial and 1041 technical resolutions; **Created D1.03** (Jul 2006 San Diego).
- Approved 568 technical resolutions (Sep 2006 Melbourne); **Created D1.06** (388p).
- Approved 703 technical resolutions (Nov 2006 Dallas); **Created D1.09 (444p).**
- Approved 496 technical resolutions (Jan 2007 London); **created D1.10 (500p)**; went to WG letter ballot Feb 7, 2007 with D 2.0; closed March 2007.

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

History of TGn

- LB97 on **TGn D2.0** passed with 83.4% approval. (Mar '07 Orlando) Began comment resolution on with target of Draft 3.0 completion and release to ballot in Sep 2007.

- Approved 1470 editorial resolutions and approved **TGn D2.02**. Also approved 450 technical comment resolutions. (May 2007 Montreal) Cumulative insertion of resolutions contained in **TGn D2.04. (494p).**

- Approved 750 technical resolutions and approved **TGn D2.05** (July 2007 San Francisco) Cumulative insertion of resolutions now contained in TGn **draft 2.07. (498p).**

- Approved 507 technical resolutions and approved recirculation ballot for **TGn D3.0** **(544p)**. (Sep 07 Waikoloa) Recirculation passed.

- Approved 282 editorial resolutions and approved TGn draft 3.01. Approved 97 technical resolutions. (Nov 07 Atlanta) Cumulative insertion of resolutions now contained in **TGn D3.02. (558p)**.

- Approved 313 technical comment resolutions (Jan 08 Taipei). Cumulative approved comments now in **D3.03**.Additional ad hoc comment resolutions contained in speculative edits **D3.04, D3.05, D3.06**.

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

History of TGn

Bits in QoS Control field		Meaning
Bit 5	Bit 6	
0	0	Normal Ack or Implicit Block Ack Request. In an MPDU that is a non-AMPDU frame: The addressed recipient returns an ACK or QoS +CF-Ack frame after a short interframe space (SIFS) period, according to the procedures defined in 9.2.8~~,~~ ~~9.3.3~~ and 9.9.2.3. ~~The Ack Policy subfield is set to this value in all directed frames in which the sender requires acknowledgment.~~ For QoS Null (no data) frames, this is the only permissible value for the Ack Policy subfield. In an MPDU that is part of an A-MPDU: The addressed recipient returns a BlockAck MPDU, either individually or as part of an A-MPDU starting a SIFS after the PPDU carrying the frame, according to the procedures defined in 9.2.8a (BlockAck procedure), 9.10.7.5 (Generation and transmission of BlockAck by an HT STA), 9.10.8.3 (Operation of HT-delayed Block Ack), 9.14.3 (Rules for the RD initiator), 9.14.4 (Rules for the RD responder) and 9.17.3 (Explicit feedback beamforming).

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

802.11n Timeline Events

EVENT NAME	CURRENTLY PUBLISHED DATE	
	ACTUAL	PREDICTED
PAR Approved	Sep '03	
Initial WG Letter Ballot	Mar '06	
Recirculation WG Letter Ballot	Oct '07	
Form Sponsor Ballot Pool		Mar '08
Initial Sponsor Ballot		Jul '08
Recirculation Sponsor Ballot		Nov '08
Final WG Approval		Mar '09
Final EC Approval		Mar '09
RevCom/ Stds Board Approval		Jun '09
Publication		Jul '09

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

802.11n Characteristics

PHY Mandatory Features

- Mandatory Features.
  - **Spatial Division Multiplexing through MIMO.**
  - 16 Modulation and Coding Schemes (MCS).
  - **1 and 2 spatial streams.**
  - 800ns GI (guard interval).
  - **20 MHz Channel Width.**
  - **Legacy and Mixed mode frame format.**
  - Channel Sounding.
  - RIFS (Reduced Interframe Space).

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

CTTC

Centre Tecnològic de Telecomunicacions de Catalunya

PHY Optional Features

- Optional Features.
  - **Up to 4 spatial streams.**
  - **40/20 MHz Channel Width support.**
  - Short GI (400ns).
  - Spatial Mapping.
    - Transmit Beam forming.
    - Spatial Expansion.
    - STBC (Space-Time Block Code).
  - Green Field frame formats.
  - Advanced Coding.
  - Low Density Parity Check Code.

Bandwidth expansion

- Legacy 20MHz.
  - 52 subcarriers (48 data, 4 pilot).
- HT 20MHz
  - 4 additional subcarriers, 56 in total (52 data, 4 pilot).
  - Rate Increased by 8% (4/48).
- HT 40MHz.
  - Two adjacent 20 MHz.
  - 10 additional subcarriers, 114 in total.
  - Remove 2 pilot subcarriers (108 data, 6 pilot).
  - Rate increased by a factor of 2.25 (108/48) with respect to the legacy 20MHz channel.

Centre Tecnològic de Telecomunicacions de Catalunya

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Operation Modes

- The PHY has three operation modes:
  - Legacy mode (mandatory).
    - Packets transmitted in legacy 802.11a/g format.
  - Mixed mode (mandatory).
    - Packets are transmitted with a preamble compatible with the legacy 802.11a/g which can be decoded by legacy 802.11a/g devices. The rest of the packet has a new format.
    - The receiver shall be able to decode both legacy and mixed mode formats.
  - Green Field (optional).
    - High Throughput (HT) packets are transmitted without legacy compatible part.
    - The receiver shall be able to decode all three formats.

CTTC

Centre Tecnològic de Telecomunicacions de Catalunya

MAC Mandatory Features

- Frame Aggregation.
  - A-MPDU (many frames under one PHY header).
  - A-MSDU (many frames under one PHY/MAC header).
- Block ACK.
  - N-Immediate.
  - Implicit.
  - Compressed bit map.
- Protection Mechanisms.
  - Long NAV.
  - PHY level spoofing.
  - RIFS Protection.
  - Green Field Protection.
- MIMO power save.
- 20/40 coexistence.
- Open & CCMP Security Mode (WPA2).

MAC Optional Features

- Block ACK.
  - Delayed Block Ack.
- Protection Mechanisms.
  - L-SIG TXOP protection.
- Reverse Direction.
- PSMP (Power Save Multi-poll).
- PCO (Phased Coexistence Operation).
- **Fast Link Adaptation**.
- PHY related.
  - **Transmit Beam forming.**
  - ZLF (Zero Length Frame) Sounding.
  - Calibration.
  - **Antenna Selection.**
  - STBC Control Frames.

Centre Tecnològic de Telecomunicacions de Catalunya

CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

802.11n Certification

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

802.11n Certification

- In October 2004, the Wi-Fi Alliance announced that it would not certify IEEE 802.11n products until IEEE ratification.
  - Reflecting its support for standards-based technology.
  - Expectation at the time was that IEEE would ratify by March 2007.

- However, the situation is different:
  - Expected final ratification has been delayed.
  - Pre-standard IEEE 802.11n products are shipping, and tens of millions more are expected to enter the market in 2007 *(ABI Research).*
  - Some pre-standard products are reaching a level of maturity where interoperability testing adds value.

Certification Plan - Phase 1

- **Wi-Fi Alliance has introduced a certification program for pre-standard IEEE 802.11n products in the first half of 2007 to help ensure interoperability for a baseline set of features in the short term.**

Centre Tecnològic de Telecomunicacions de Catalunya

Centre Tecnològic de Telecomunicacions de Catalunya

Certification Plan - Phase 2

- **The Wi-Fi Alliance plans to certify products based on the final IEEE 802.11n standard when it is ratified, supporting what they expect to be a larger set of features and a fully reviewed and interoperable standards based solution.**
  - When a full IEEE 802.11n standard is available, WFA will work toward support of compatibility with pre-standard certified products to help ensure positive user experience.
  - The maturity of baseline features in the pre-standard certification diminishes the risk that certified pre-standard products will not comply with the final IEEE 802.11n standard.

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Certified 802.11n products

260 product(s) meet your search criteria. New Search | Simple Search

3com

Product	Date Certified	Category	
• 3Com Wireless 11n USB Adapter	02/20/2008	External Wi-Fi Adapter Card	View Wi-Fi Certifications
• 3Com Wireless 11n PCI Card	02/20/2008	Internal Wi-Fi Adapter Card	View Wi-Fi Certifications

amit
Navigator of Digital Life

Product	Date Certified	Category	
• Wireless Broadband 11n Router	12/31/2007	Access Point for Home or Small Office	View Wi-Fi Certifications

Product	Date Certified	Category	
• AirPort Extreme Base Station with 802.11n (Gigabit Ethernet)	08/15/2007	Access Point for Home or Small Office	View Wi-Fi Certifications
• AirPort Extreme Base Station with 802.11n (Fast Ethernet)	08/23/2007	Access Point for Home or Small Office	View Wi-Fi Certifications
• Time Capsule	03/20/2008	Access Point for Home or Small Office	View Wi-Fi Certifications
• AirPort Express with 802.11n	03/31/2008	Access Point for Home or Small	View Wi-Fi Certifications

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Certified 802.11n products

Wi-Fi® Interoperability Certificate — **Certification ID: WFA5439**

This certificate indicates the capabilities and features that successfully completed interoperability testing by the Wi-Fi Alliance. You may find detailed descriptions of these features at www.wi-fi.org/certification_programs.php.

Certificate Date: August 15, 2007
Category: Access Point for Home or Small Office (Wireless Router)
Company: Apple
Product: AirPort Extreme Base Station with 802.11n (Gigabit Ethernet)
Model/SKU#: MB053

This product has passed Wi-Fi certification testing for the following standards:

IEEE Standard	Security	Multimedia	
802.11a	WPA™ - Personal	WMM®	
802.11b	WPA™ - Enterprise		
802.11g	WPA2™ - Personal		
802.11n draft 2.0	WPA2™ - Enterprise		
	EAP Type(s)		
	EAP-TLS		
	EAP-TTLS/MSCHAPv2		
	PEAPv0/EAP-MSCHAPv2		
	PEAPv1/EAP-GTC		
	EAP-SIM		

For more information: www.wi-fi.org/certification_programs.php

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Certified 802.11n products

- When the final standard is ratified the Wi-Fi Alliance plans to support backward compatibility with pre-standard certified products.

- Wi-Fi CERTIFIED 802.11n draft 2.0 gear is backward-compatible with Wi-Fi CERTIFIED 802.11 a/b/g gear that operates in the same frequency bands.

- Wi-Fi buyers should seek Wi-Fi CERTIFIED® products that meet their needs.

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

802.11n Electricity Issues

Electricity issues

- Most 802.11n systems due to multi radio require more power than a typical Ethernet switch—based on the 802.3af standard—can provide.

- Current PoE (Power over Ethernet) specifies a maximum device support of no more than 12.95 watts, therefore any device powered by PoE should not consume more than that. But 802.11n access points use 15 to 18 watts→ reduce functionality and lose 40%.

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Electricity issues

- Siemens cracks 802.11n power problem (Siemens has entered the 802.11n (3x3MIMO) that doesn't require a power upgrade.

- Cisco´s solution involves injecting additional wattage onto an AP's wired connection, either through 1250-specific power injectors or the enhanced PoE capabilities available in its flagship Catalyst 3750-E and 3560-E switches.

- **New standard 802at.**

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Links of interest

- **802.11n Standardization Group**
  http://grouper.ieee.org/groups/802/11/
- **Wi-Fi Alliance**
  http://www.wi-fi.org/

- **CTTC**
  www.cttc.es
- **Access Technologies Area**
  www.cttc.es/wiki/access

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Thanks for your kind attention!

Christos Verikoukis, Ph.D.

Senior Research Associate

Telecommunications Technological Center of Catalonia

Mediterranean Technological Park

Av. del Canal Olímpic, s/n

08860 Castelldefels – Spain

Web page:www.cttc.es/wiki/access/ index.php/Christos_Verikoukis

e-mail:cveri@cttc.es

CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

Additional slides

CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

Functional Requirements

Requirement	Description
HT rate supported in 20MHz channel	at least one mode of operation supports 100Mbps throughput at the top of the MAC SAP in a 20 MHz channel
Works in the 5 GHz bands	Protocol supports 5GHz bands (including those supported by .11a)
.11a backwards compatibility	Some of the modes of operation defined in the proposal should be backwards compatible with .11a
.11g backwards compatibility	in 2.4 GHz, some of the modes of operation defined in the proposal should be backwards compatible with .11g

CTTC
Centre
Tecnològic
de Telecomunicacions
de Catalunya

Functional Requirements

Requirement	Description
.11e QoS support	The proposal must permit implementation of the 802.11e options within a .11n STA
Spectral Efficiency	The highest throughput mode of the proposal should achieve a spectral efficiency of at least 3 bps/Hz for the PSDU
Control of support for legacy STA from .11n AP	A .11n AP can be configured to reject or accept associations from legacy STA because they are legacy STA