Wireless Links: Properties, Challenges, Standards, and Evolution

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My Background

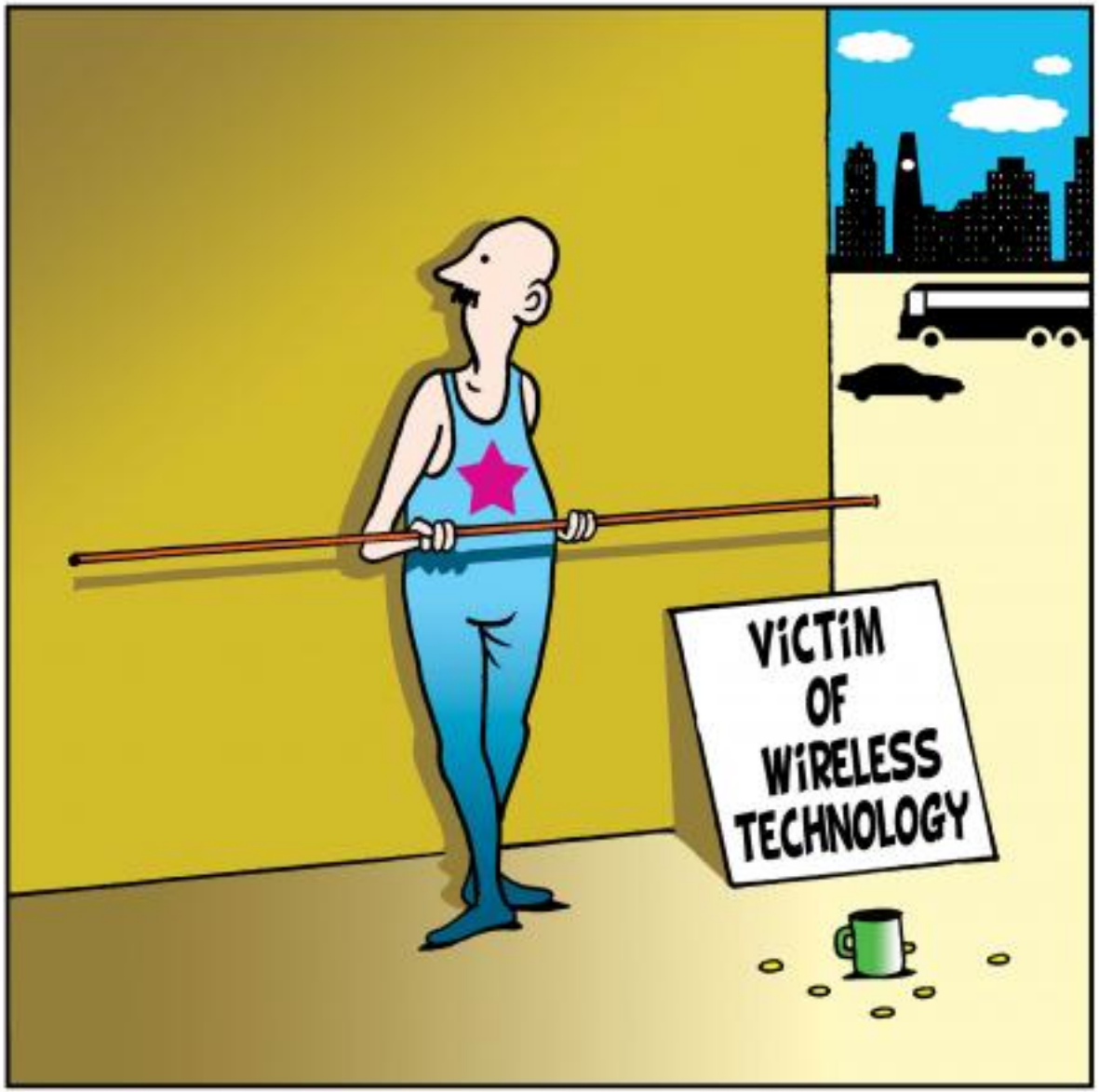
- My wireless back ground is almost entirely in IEEE 802.11
  - Current Chair of 802.11ak (General Link)
  - Former Chair of 802.11s (Mesh)
- IETF background
  - Current Chair of TRILL WG
  - Former Chair of PPPEXT, TRADE, XMLDSIG, Nomcom
- Principal Engineer at Huawei
  - Formerly Cisco, Motorola

Scope and Disclaimer

- This talk will cover the more prominent general characteristics of wireless links, current and previous IETF work related to wireless links, and the IEEE 802.11 and 802.15 WGs and their activities.
- Assumes general familiarity with the IETF.
- This talk represents my views, not those of Huawei Technologies or the IETF or IEEE 802 or sub-parts of those organizations.

Topics

- Wireless Link Properties
- Wireless Related IETF WGs
  - Current, Concluded
- 802 Wireless Current Work
  - 802.11 Wireless Local Area Network (WLAN)
  - 802.11ak – General Link
  - 802.15 Wireless Personal Area Network (WPAN)
- References & Acknowledgements


VICTIM
OF
WIRELESS
TECHNOLOGY

Wireless Link Control Categories

- Two main control categories:

1. Dictatorial
   - Central control in cells or trunked systems
   - Typical of cellular phone, Wi-Max (802.16)…
   - Licensed spectrum
2. Democratic
   - Multiple paradigms: ad-hoc pairwise communication, Access Point coordination, mesh, …
   - Typical of Wi-Fi (802.11), BlueTooth/Zigbee (802.15)
   - Unlicensed spectrum

Wireless Link Control Categories

- As usual, it is actually more complicated. There is overlap such as democratic protocols used in licensed bands and dictatorial modes of democratic protocols or the like.
- Centralized dictatorial systems can precisely allocate time slots but typically have a contention slot for new stations to call in.
- Even when a democratic protocol is operating in a centralized mode, such as coordination by a Wi-Fi access point, it if normal for a competing sets of stations on the same frequencies to appear.

Common Link Characteristics

- Packet loss rates are orders of magnitude higher and more variable than wire/fiber
  - Rayleigh / Rican fading
- With some glitches due to absorption bands
  - Higher frequencies are more line-of-sight with less ability to penetrate obstacles
  - Lower frequencies have greater ability to penetrate or go around obstacles

Common Link Characteristics

- If you are close, it is trivial to observe or block genuine messages or inject false messages
- Physically multi-access with different data rate / cost to different stations
  - Can be reduced by directional transmission/reception
- Mobility (not so much for central sites or APs themselves)
  - Roaming, secure handover requirements

Common Wireless Protocol Features

- Discovery:
  - You don't have a hard path to your neighbors. So, you generally have to do passive scanning (listening) or active scanning (probing) at multiple frequencies to find them. May need to find out what services they offer and what credentials they will accept before you have authenticated to them.
  - Typically coordination or peer nodes send "beacon" messages periodically and/or respond to "probe" messages.

Common Wireless Protocol Features

- Reliability:
  - High variability with time, distance, obstacles, etc. means that for performance and reliability you need
    - Link level acknowledgements and re-transmission
    - Adaptable rate, modulation, and power for different stations and as conditions change
    - Packet fragmentation or aggregation depending on conditions

Common Wireless Protocol Features

- Access Security:
  - Authentication / registration between a client and a base station or between peers is commonly required.
    - Typically there is a process of Association / De-association / Re-association
  - If nodes support voice calls, an access security by-pass for emergency calls will be required in many countries.

Common Wireless Protocol Features

- Data Security:
  - Easy eavesdropping, blocking, and injection make good default security important. Commonly encryption/authentication crypto primitives implemented in hardware:
    - Good because that makes the crypto “free” (very little CPU load).
    - Bad because changing algorithms may require changing hardware.

Common Wireless Protocol Features

- Mesh:
  - Dictatorial control regimes typically impose a centralize one-hop or multi-hop tree structure. But democratic control usually provides a mesh mode.
  - Can give you:
    - Greater wireless range due to relaying.
    - Higher bandwidth due to shorter hops.
    - Better battery life due to lower power.
  - Provides cheaper backhaul which, combined with "free" clients, can be leveraged to provide ultra low cost services. Fewer wires yields greater mobility.

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MUST HAVE SOMETHING TO DO WITH WIRELESS TECHNOLOGY..

Wireless Related IETF WGs

- Some concluded IETF WGs and currently 10 active IETF WGs related to Wireless:
  - CORE, PAWS, 6LOW, 6LOWPAN, 6TISCH, LWIG, MIF, MANET, ROLL, and DICE.
- Many relate to highly constrained devices, mostly battery powered wireless stations.
- Mobility and variability of topology is another factor. IP mobility WGs are generally not listed here.
- Mobility + security leads to secure handoff/roaming, for example between cellular and Wi-Fi or wired and wireless.

Current IETF WGs

- APP Area
  - CORE – Constrained RESTful Environments
    - Most of the “constrained” work is motivated by low power / cheap radio nodes. This is a web profile for such devices.
  - PAWS – Protocol to Access White Space
    - “White Space” idea is to use various spatial gaps in Television broadcast use, for example. Current trend is toward having much of this controlled by a database.

Current IETF WGs

- INT Area
  - 6LOW = IPv6 over Networks of Resource-constrained Nodes
    - 6low focuses on the work that facilitates IPv6 connectivity over constrained node networks with the characteristics of:
      - limited power, memory and processing resources
      - hard upper bounds on state, code space and processing cycles
      - optimization of energy and network bandwidth usage
      - lack of some layer 2 services like complete device connectivity and broadcast/multicast

Current IETF WGs

- INT Area (continued)
  - 6LOWPAN = IPv6 over Low power WPAN
    - Aimed at sensor / control networks with very low power (batteries lasting years without re-charge) and device cost (total cost is single digit dollars).
      - More devices than current LANs.
      - Severely constrained code/RAM space, processing, such as 32K flash memory, 8-bit micoprocesor.
    - 6LOWPAN: Overview, Assumptions, Problem Statement, and Goals [RFC4919]
    - IPv6 Packets over IEEE 802.15.4 [RFC4944]

Current IETF WGs

- INT Area (continued)
  - 6TISCH =
    IPv6 over the TSCH mode of IEEE 802.15.4e
    - IEEE 802.15.4e Timeslotted Channel Hopping (TSCH) is the emerging standard for industrial automation and process control low power and lossy networks.

Current IETF WGs

- INT Area (continued)
  - LWIG =
    Light Weight Implementation Guidance
    - The purpose of the LWIG working group is to collect experiences from implementers of IP stacks in constrained devices.

Current IETF WGs

- INT Area (continued)
  - MIF = Multiple Interfaces
    - Hosts (end stations) with multiple interfaces to different networks.
    - Mostly applicable due to wireless links: smart phone on cellular and Wi-Fi (and Blue tooth) links simultaneously; laptop on Ethernet and Wi-Fi.

Current IETF WGs

- RTG Area
  - MANET = Mobile Ad-Hoc Networks
  - Developing re-active and pro-active routing suitable for wireless routing applications in topologies with increased dynamics due to node motion or other factors.
    - AODV, Ad Hoc On-Demand Distance Vector
    - OLSR, Optimized Link State Routing

Current IETF WGs

- RTG Area
  - ROLL =
    Routing Over Low power and Lossy networks
    - Limited power, memory, and processing.
    - Nodes interconnected by a variety of links, such as IEEE 802.15.4, Bluetooth, Low Power Wi-Fi, PLC (Powerline Communication) or similar links.

Current IETF WGs

- SEC Area
  - DICE = DTLS in Constrained Environments
    - (DTLS [RFC6347] = Datagram Transport Layer Security)
    - Constrained environments looked at in DICE include constrained devices (e.g. memory, algorithm choices) and constrained networks (e.g. PDU sizes, packet loss).

Concluded IETF WGs

Some wireless related concluded WGs:

- INT area
  - 6ng = IP over IEEE 802.16 networks
  - MOBILEIP = IP Routing for Wireless/Mobile Hosts
  - (several other mobility WGs)
- OPS area
  - CAPWAP =
    Control And Provisioning of Wireless Access Points
- SEC area
  - HOKEY = Handover Keying

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IETF IEEE Comparison

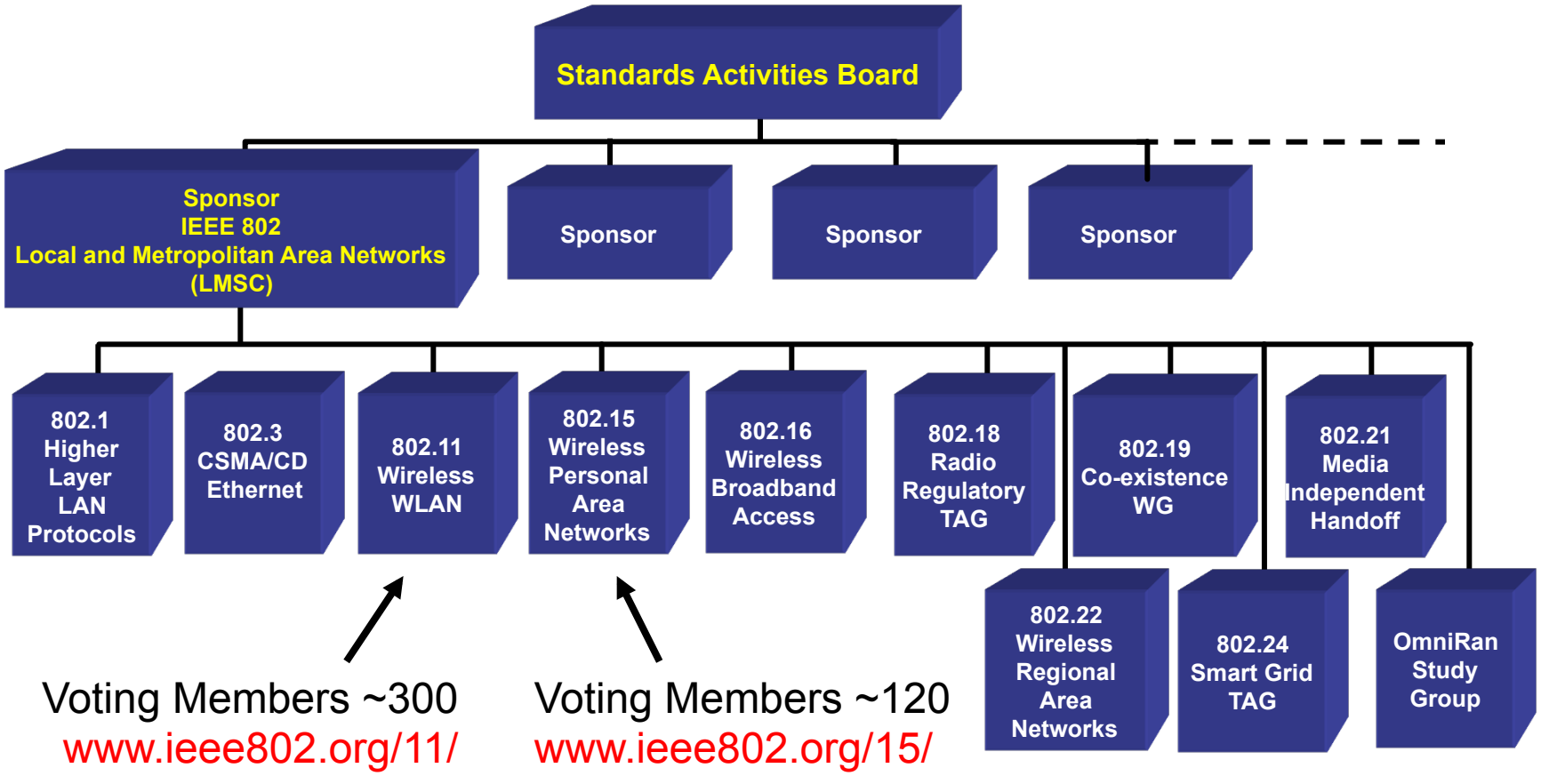
- These are rough equivalencies
  - IETF Area ≈ IEEE 802 WG
  - IETF WG ≈ Task Group within an 802 WG
- IEEE 802 very physical meeting oriented, WGs have voting membership by individuals, ¾ vote required to resolve technical disagreements
- IETF more mailing list oriented, not defined WG membership, uses rough consensus

IETF IEEE Comparison

- IETG WG Charter ≈ IEEE PAR (Project Authorization Request)
- Since versus multiple documents
  - IEEE: A PAR authorized the creation of one document. Amendments are mechanical editing instructions to a document as modified by all previously approved and not yet rolled in amendments. So IEEE tends to have massive standards document which can be hard to understand.
  - IETF: Much more liberal about creating documents and updates. So IETF tends to have multiple related RFCs that can be hard to understand in the aggregate.

IEEE 802 Wireless

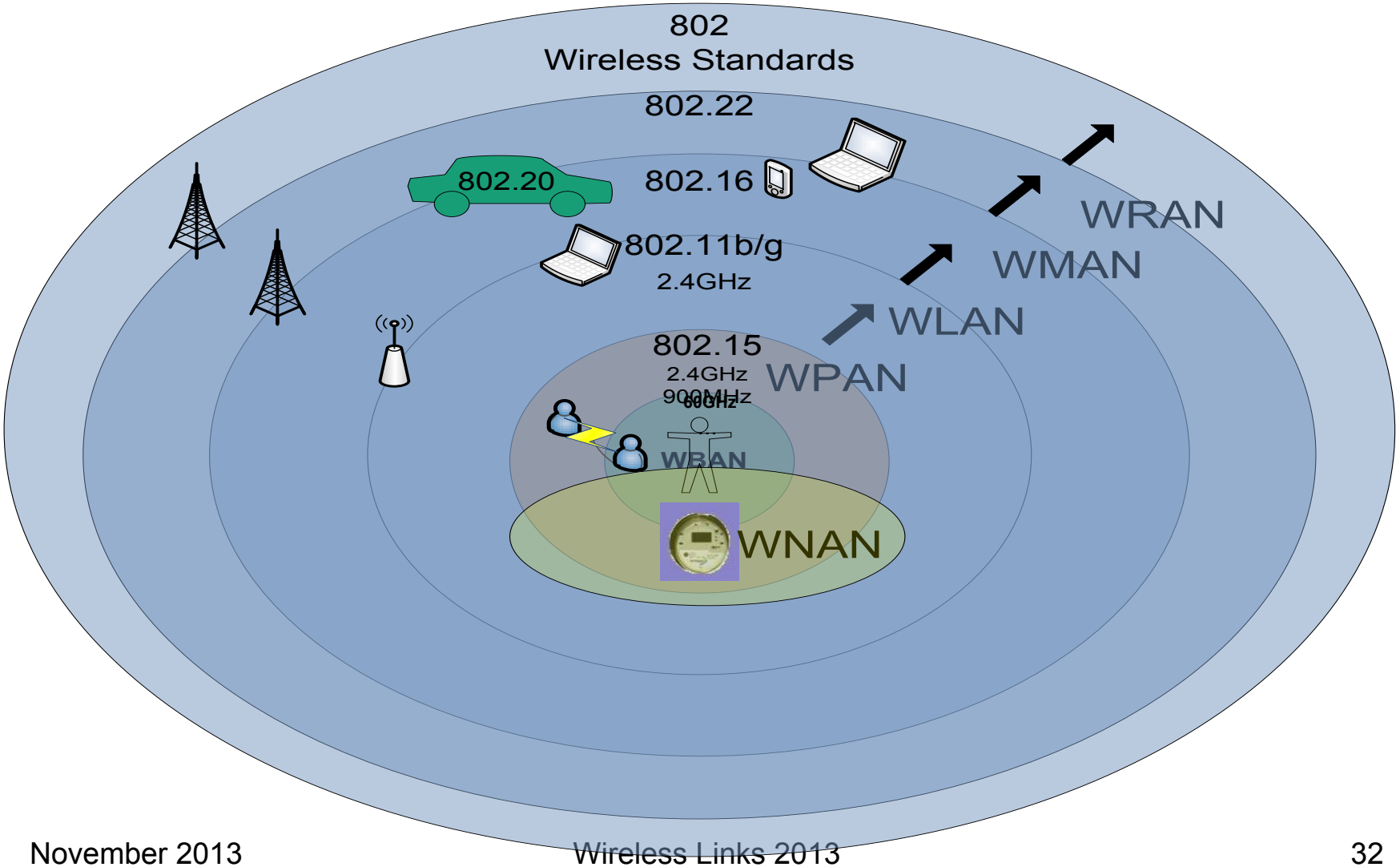
IEEE Standards Association



Voting Members ~300
www.ieee802.org/11/

Voting Members ~120
www.ieee802.org/15/

IEEE 802 Wireless



Industry Consortia

Provide profiling, certification testing, interoperability trials, branding, marketing, etc.

Standard	W * AN	Industrial Alliance
802.11	Local (WLAN)	Wi-Fi Alliance
802.15.1	Personal (WPAN)	Bluetooth SIG
802.15.3	Personal (WPAN)	
802.15.4	Personal (WPAN)	ZigBee Alliance
802.16	Metropolitan (WMAN)	Wi-Max
802.22	Regional (WRAN)	

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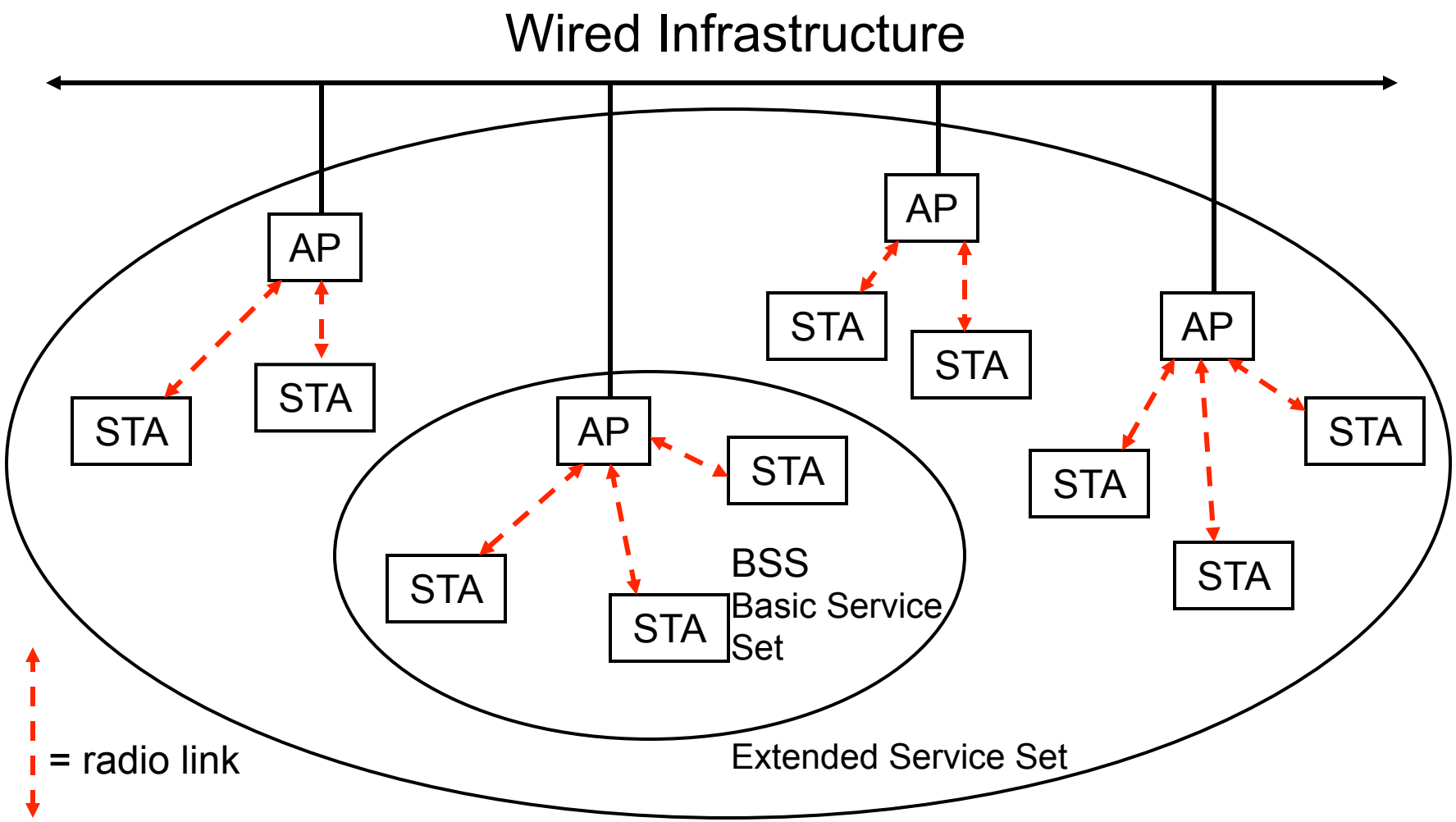
IEEE 802.11™, "Wi-Fi"

- Originally conceived to link wireless cash registers
- Today underpins revolutionary mobile devices and ever-growing range of applications

802.11 is the new Ethernet

- "Everything" has 802.11 built in, laptops, smartphones, etc. Clients are "free".
- Like Ethernet, 802.11 is way down the price and learning curve.
- Like Ethernet, 802.11 was a simple best-effort contention based protocol.
  - But, like Ethernet, it is being stretched to do what it shouldn't, wouldn't, couldn't do: QoS, Mesh, Security, Vehicular Mobility, Faster Rates, Fast Roaming, Etc.
- "Free" Wi-Fi increasingly ubiquitous: in Taxis, Buses, Airports.
- Wi-Fi is being extended to car-to-car communications, vehicular traffic control, etc.

Classic ESS


Wired Infrastructure
AP
AP
AP
STA
STA
STA
STA
STA
STA
STA
STA
STA
STA
STA
BSS
Basic Service
Set
Extended Service Set
= radio link

Wi-Fi Alliance

- Founded in 1999
- 500+ member companies

The Wi-Fi Alliance provides:

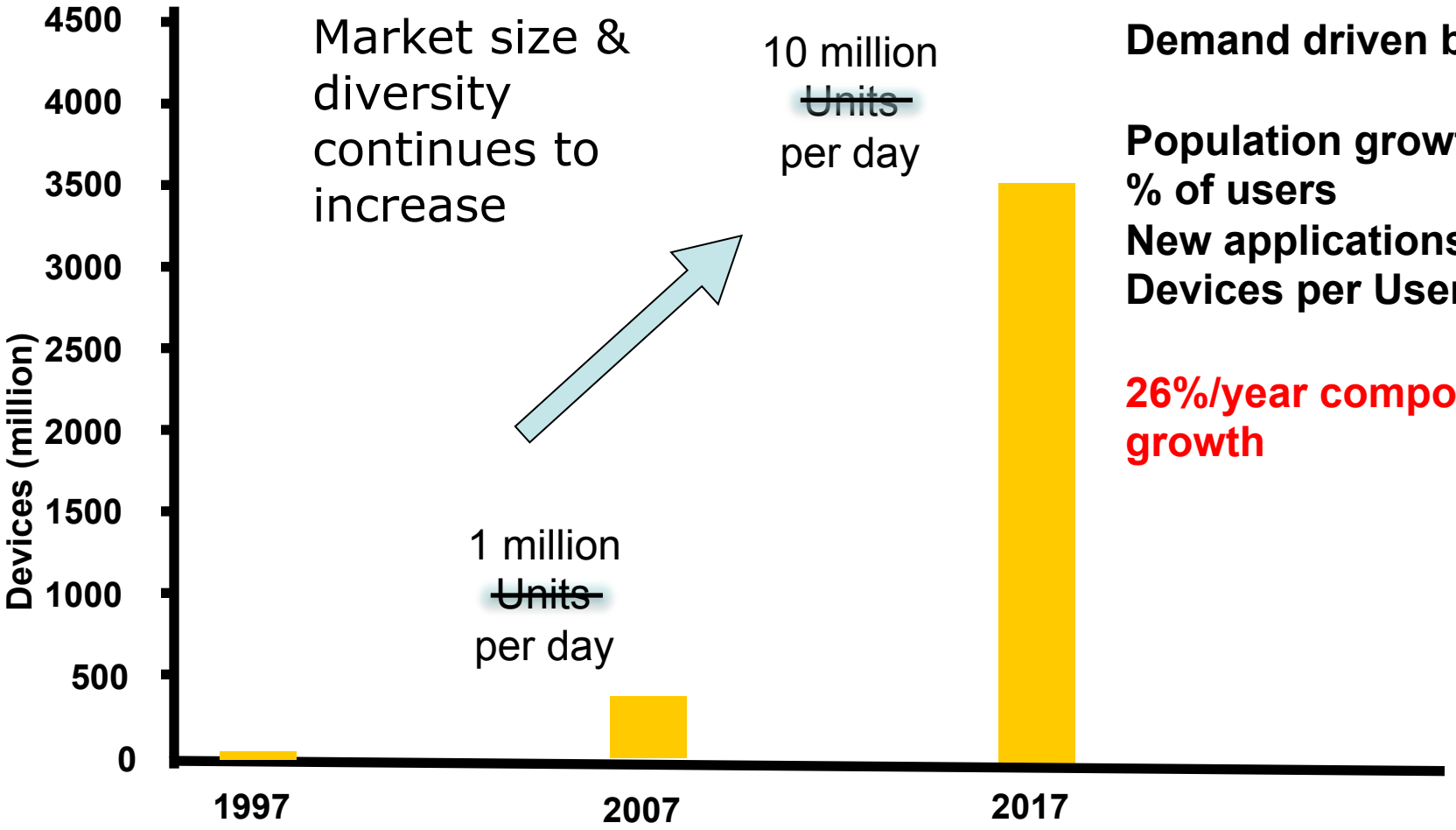
  - *Interoperability certification programs*
    - *Over 9000 products certified*
  - *Market messaging*
- *Early alliance slogan was "The standard for Wireless Fidelity"*

http://www.wi-fi.org/

826,480 hot spots in 144 countries

Source: JiWire
http://v4.jiwire.com/search-hotspot-locations.htm

802.11 Device Volume Growth



Demand driven by:

Population growth
% of users
New applications
Devices per User

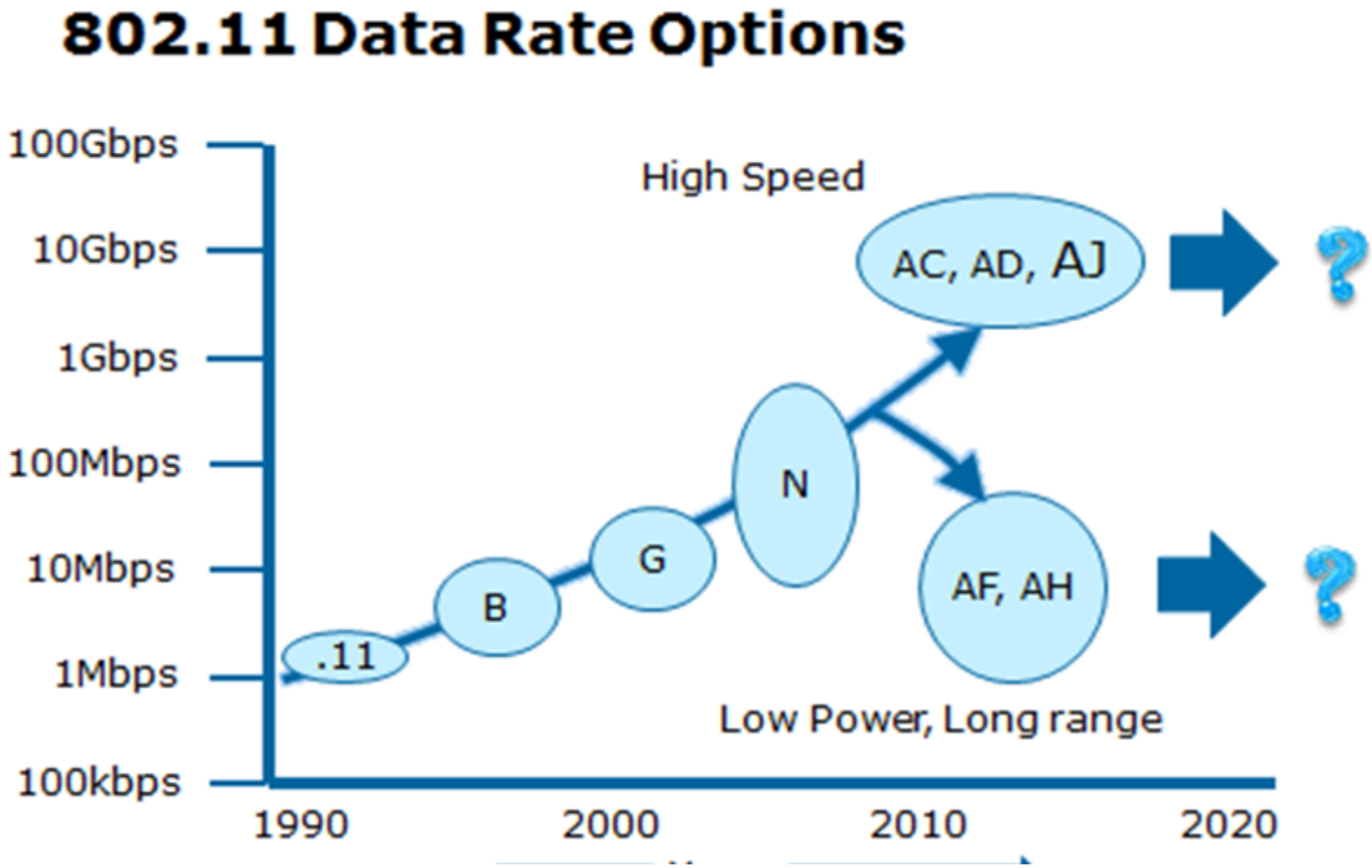
26%/year compound growth

Source ABI

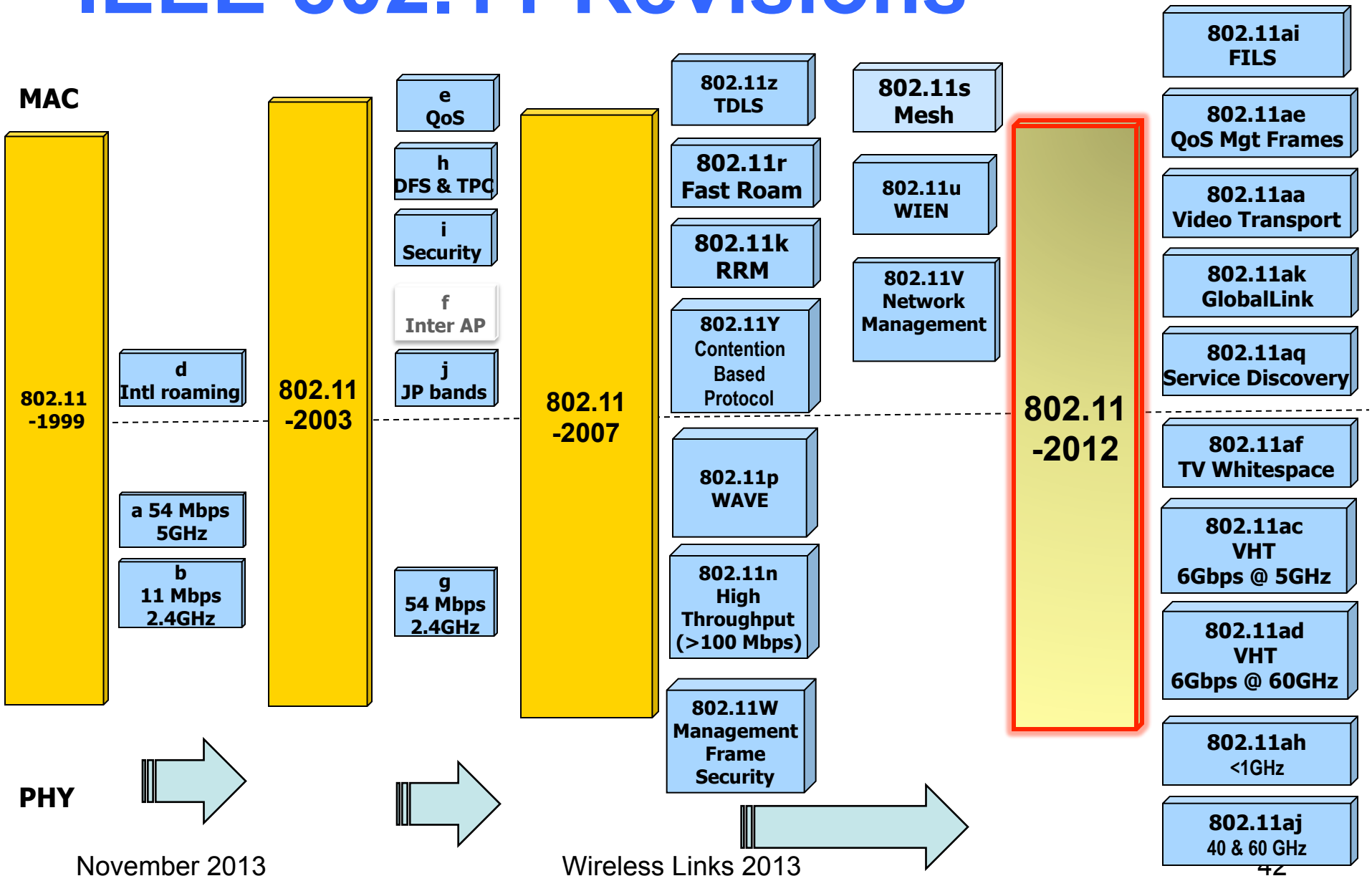
802.11Active Groups

Type	Group	Description	Chair
WG	WG11	The IEEE 802.11 Working Group	Bruce Kraemer
TG	MC	Maintenance – Revision "mc"	Dorothy Stanley
TG	AC	Very High Throughput (<6 GHz bands)	Osama Aboul-Magd
TG	AF	Operation in TV Whitespace bands	Richard Kennedy
TG	AH	Operation in 900 MHz bands	Dave Halasz
TG	AI	Fast Initial Link Setup	Hiroshi Mano
TG	AJ	China 60 GHz	Xiaoming Peng
TG	AQ	Pre-association Discovery	Stephen McCann
TG	AK	General Link	Donald Eastlake
SC	WNG	Wireless Next Generation	Clint Chaplin
SC	ARC	Architecture	Mark Hamilton
SC	JTC1	ISO/IEC/JTC1/SC6 shadow committee	Andrew Myles
SC	REG	Regulatory	Richard Kennedy
SG	HEW	High Efficiency WLAN	Osama Aboul-Magd

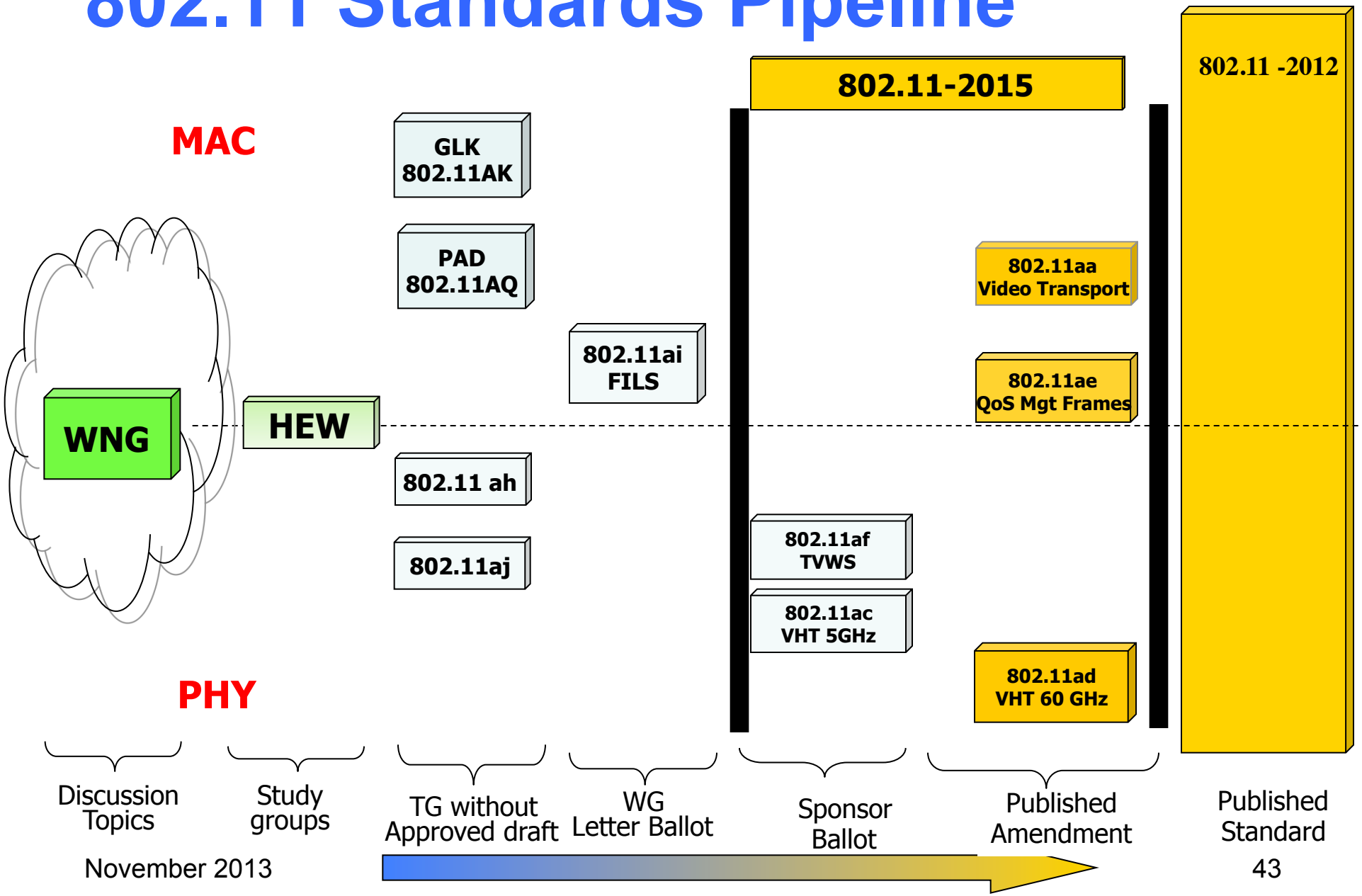
802.11 Data Rates



IEEE 802.11 Revisions

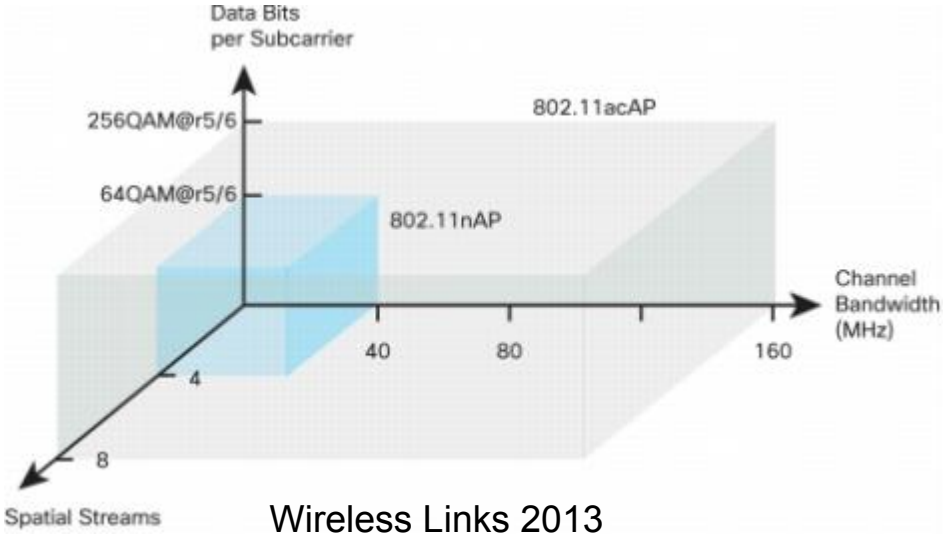


802.11 Standards Pipeline



802.11 Bandwidth Technology

Feature		802.11	11n	11ac
Bits per subcarrier		1,2		
Streams		1	4	8
Modulation		BPSK, QPSK	BPSK to 64 QAM	BPSK to 256 QAM
Data rate (maximum)	Mbps	1,2	600	6700
Channel Bandwidth	MHz	20	20,40	20,40,80, 160



IEEE 802.11 Spectrum

- 802.11 initial – 2.4 GHz
- 802.11a – 5 GHz
- 802.11j – 4.9-5 GHz Japan
- 802.11-2007 – Licensed 4.9 GHz US
- 802.11y – 3.65-3.7 GHz US operation
- 802.11af – TV White Space
- 802.11ah – Sub 1 GHz
- 802.11aj – Chinese Millimeter Wave

Wi-Fi Security

- WEP – a disaster
- Profiling of an early 802.11i Draft (WPA)
- 802.11i (WPAv2) – Robust Data Security
- 802.11r – includes security for rapid roaming
- 802.11w – Protected Management Frames
- 802.11s – symmetric peer-to-peer security for mesh stations

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IEEE 802.11ak: General Link

- Currently IEEE 802.11 links are designed to be at the edge of the network, with the exception of 802.11 mesh.
- The goal of 802.11ak is to make 802.11 links usable in the middle of a general network. And, as a practical matter, people are primarily interested in using AP – Station (STA) links.

IEEE 802.11ak: General Link

- There are a number of problems to be solved:
  - Addressing – existing AP infrastructure 802.11 frames do not have enough addresses for accessing end stations behind a non-AP STA (~station).
  - Sub-setting – various requirement for a multi-desination frame from an AP to be received by a subset of the stations associated with that AP
  - Tagging – existing 802.11 frames use LLC (802.2 style) tagging, not Ethertype encoding

IEEE 802.11ak: General Link

- Other 802.11ak Considerations
  - Model of link and reporting of costs to the rest of the network
    - A bundle of point-to-point links plus a special broadcast port or a multi-access link?
    - Unequal costs between pairs of stations that can all hear each other?
    - Generally wired links should be used in preference to wireless. Perhaps use a combination of pessimism and hysteresis in reporting wireless link costs.
  - Quality of Service mapping, particularly between 802.3 Ethernet and 802.11

IEEE 802.11ak: General Link

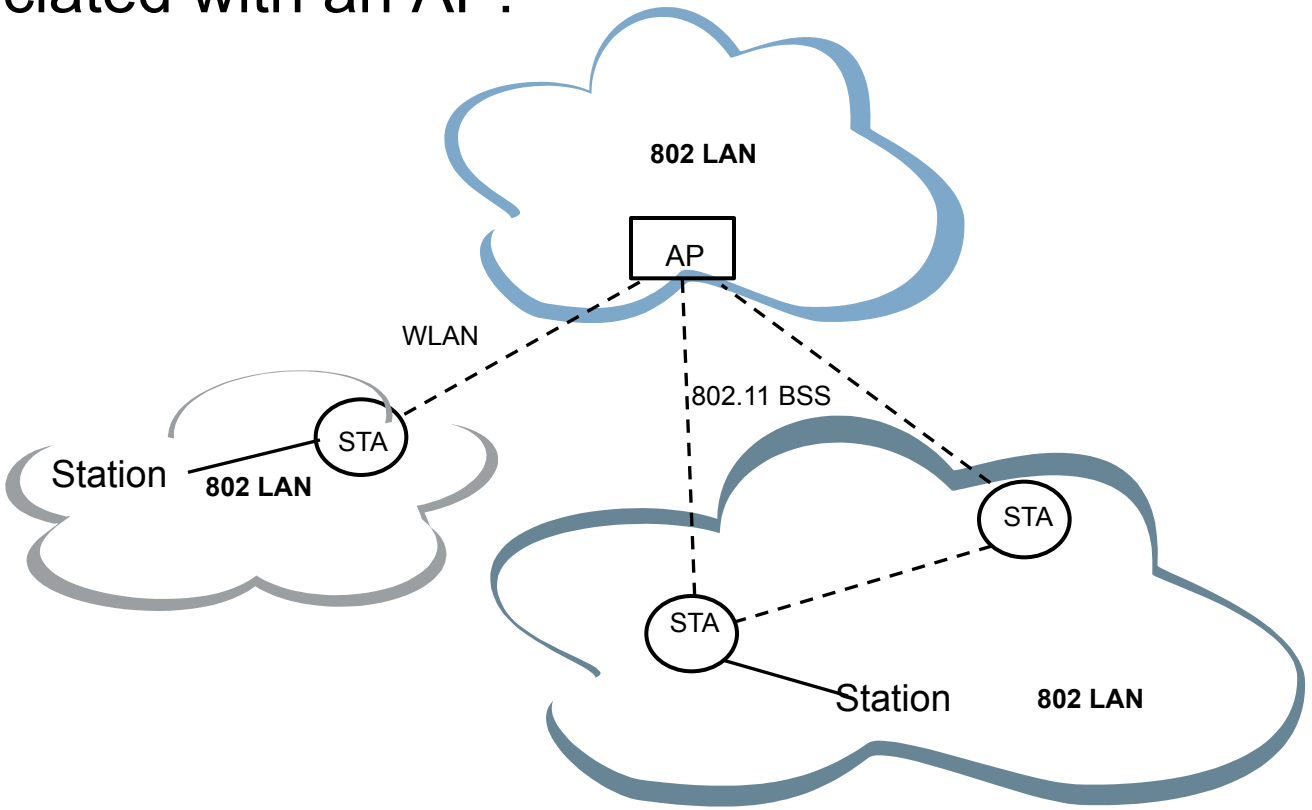
- Other 802.11ak Considerations
  - Effects on 802.1AS (precise timing) Synchronization
    - Currently it is assumed that there could be no more than two 802.11 hops in a path, the first and last. Accommodation for 802.1AS over 802.11 in 802.11aa.

IEEE 802.11ak: Addressing

- A unicast frame from a STA to an AP has three MAC fields in it, the source STA port, the AP, and the destination, which might be another STA on the same AP or a different AP in the same ESS (extended service set). For a STA to receive an unicast frame, the frame needs to address the STA wireless port.

IEEE 802.11ak: Addressing

- But you want to be able to address stations behind STAs associated with an AP:



IEEE 802.11ak: Addressing

- There are a variety of possible solutions:
  - Use the 802.11 “four address” frame format
  - Use the 802.11 frame aggregation feature (part of 802.11n) since it provides outer addresses for deliver to STA and then inner addresses that can be used for ultimate source and destination.

IEEE 802.11ak Sub-setting

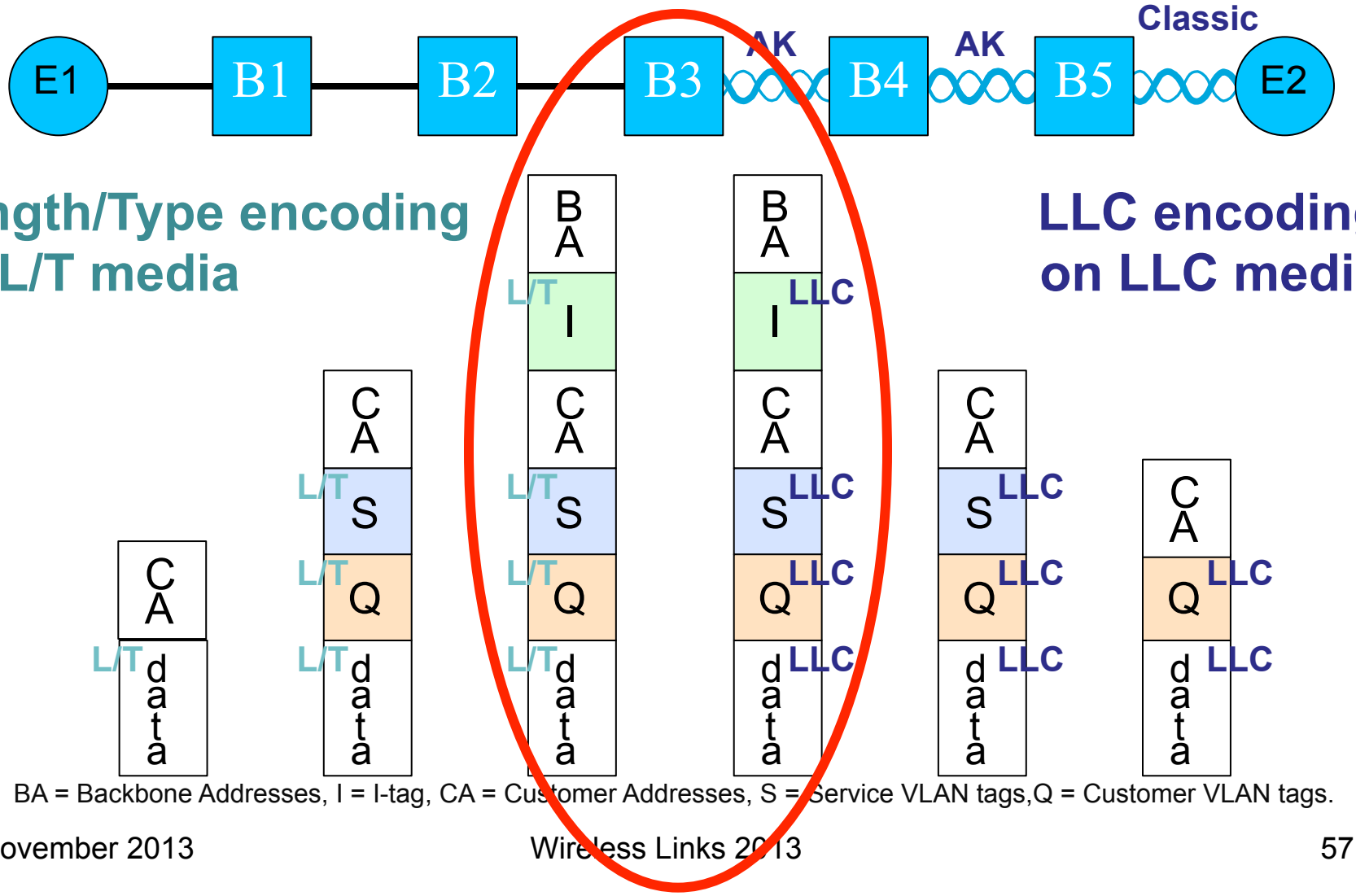
- When an AP sends a multi-destination data frame, there are reasons why only some STAs should accept it and possibly receive different versions of the frame:
  1. If it was sent to the AP by a STA, that STA should not get the data frame back (the “reflection” problem).
  2. If you are viewing communications as a bundle of point-to-point links, spanning tree or other protocols block the “p2p port” at the AP, the STA should not receive it (the “sub-setting” problem).
  3. To fully model bridge port VLAN/priority mapping, different STAs should receive the data frame with different tags or no tags (can be viewed as sub-setting for each tagging).

IEEE 802.11ak Sub-setting

- There are a couple of proposed solutions:
  - Serial multicast – inefficient.
  - Use special multicast addresses on frame to indicate which recipients. Probably requires a protocol to dynamically configure such multicast addresses.
  - Add explicit information to multi-destination frames to indicate their recipients and possibly different tagging for different recipients. Probably starts from an existing 802.11n aggregated frame format.

IEEE 802.11 Frame Tagging Problem

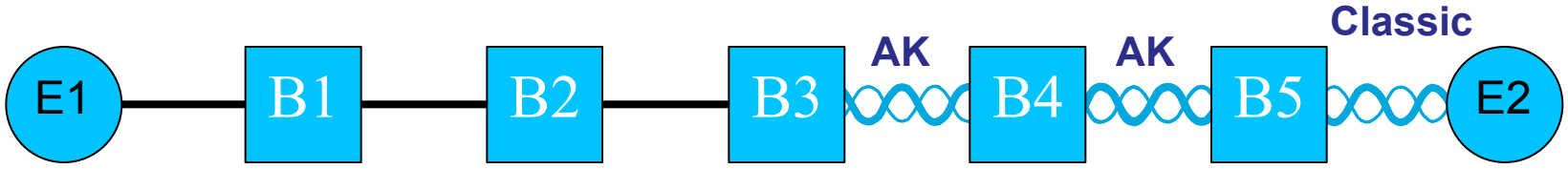
All tags must be translated at once by B3



BA = Backbone Addresses, I = I-tag, CA = Customer Addresses, S = Service VLAN tags,Q = Customer VLAN tags.

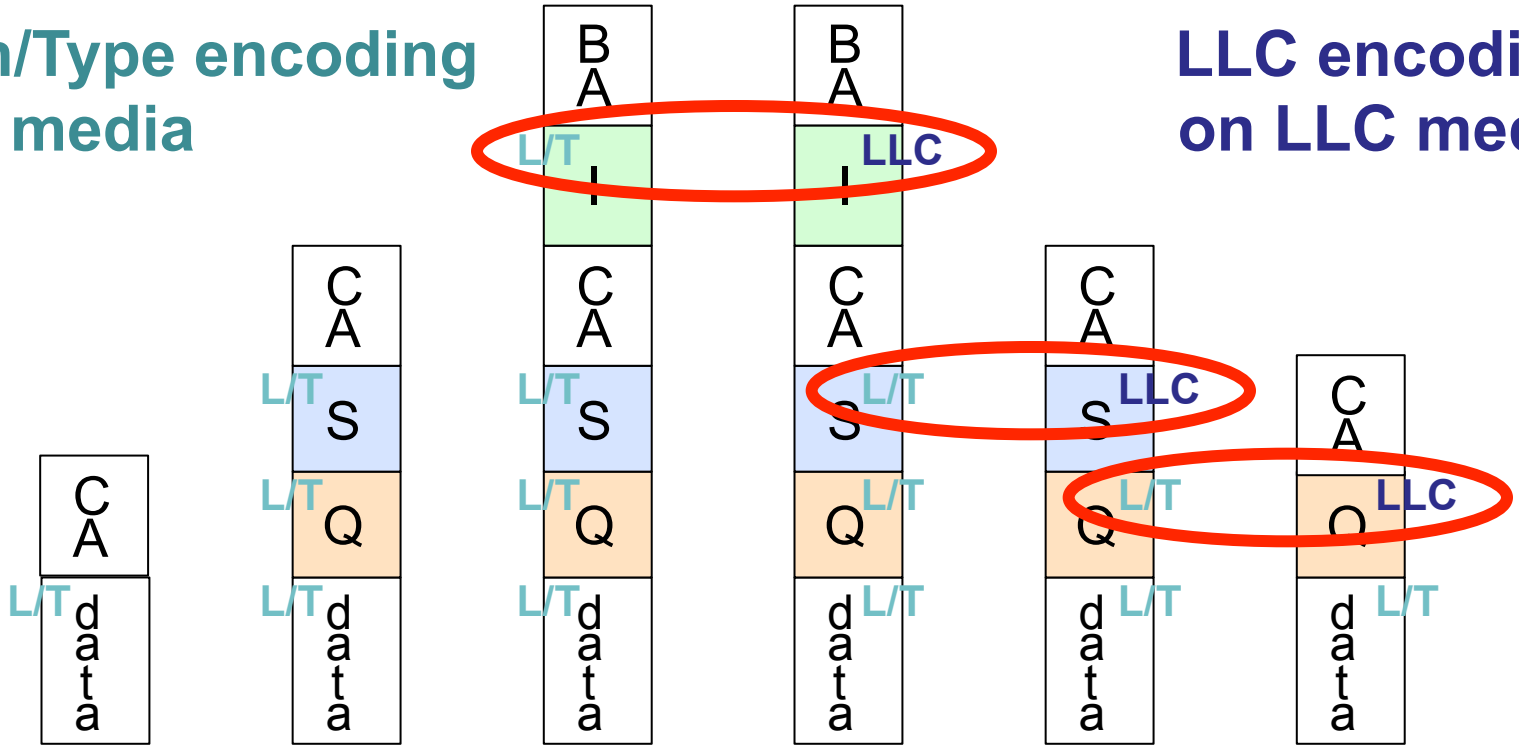
802.11 Frame Tagging, Solution 1

Translate only outer tag(s)



Length/Type encoding on L/T media

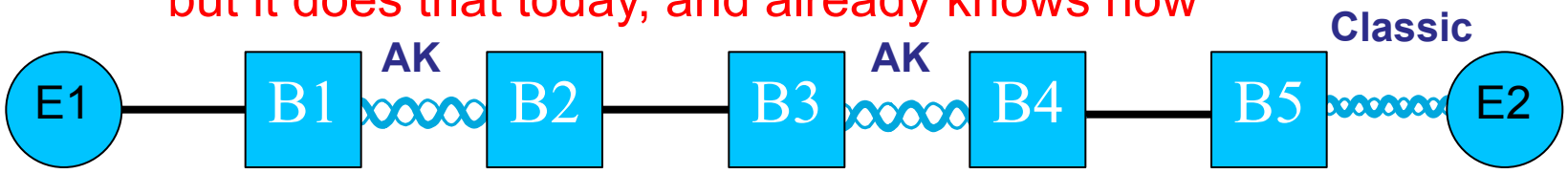
LLC encoding on LLC media



BA = Backbone Addresses, I = I-tag, CA = Customer Addresses, S = Service VLAN tags,Q = Customer VLAN tags.

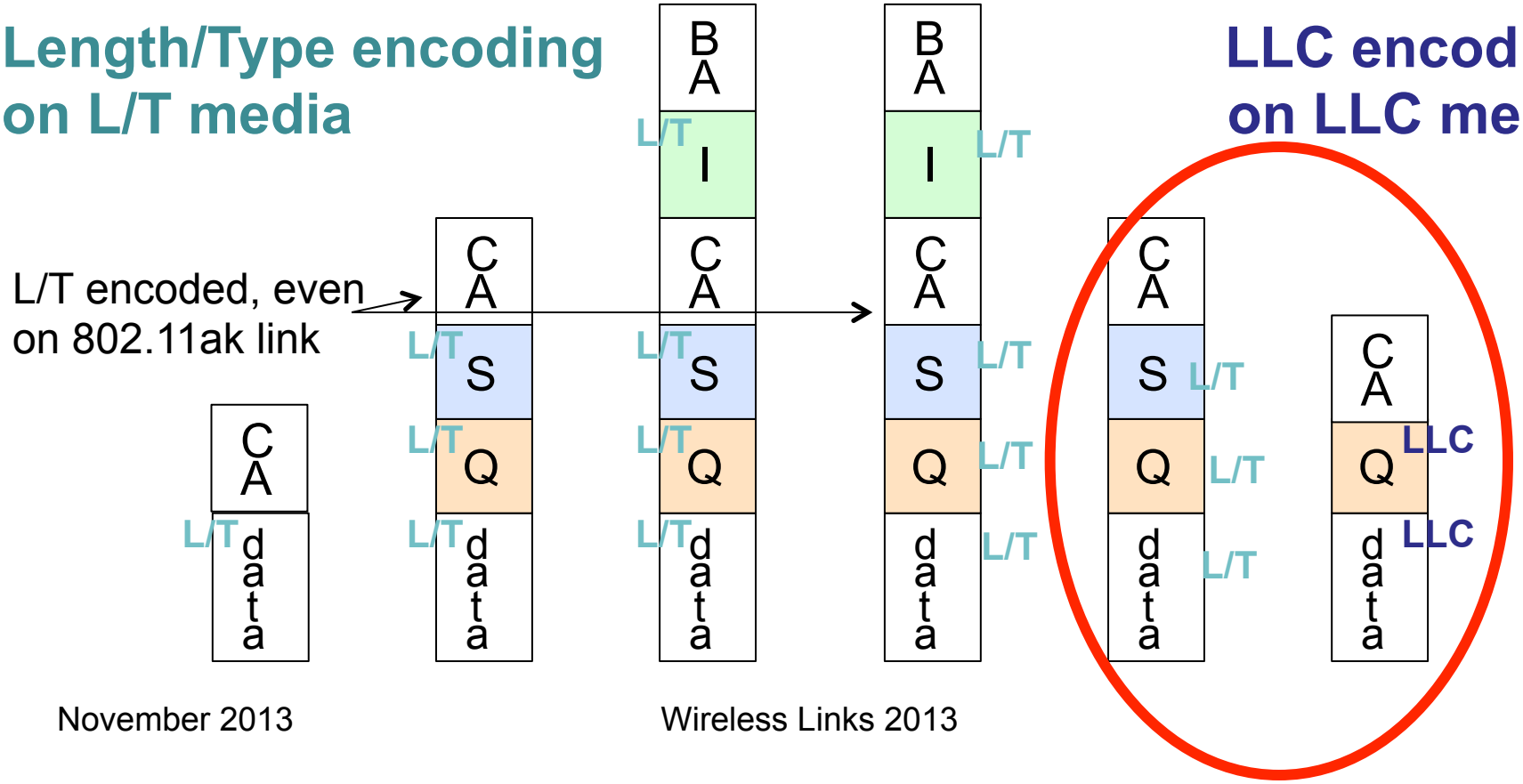
802.11 Frame Tagging, Solution 2

All remaining tags must be translated by B5,
but it does that today, and already knows how



Length/Type encoding on L/T media

LLC encoding on LLC media



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IEEE 802.15 Scope

- Initial activities focused on wearable devices with ~10 meter range, hence “personal area networks”.
- Activities have grown much more diverse and varied
  - Data rates from 2kbps to 2gbs
  - Ranges from meters to kilometers
  - Frequencies from 400MHz to 800THz
  - Frequently non-TCP/IP applications
- Focus is on “specialty”, typically short range, communications. If it is wireless and not a LAN, MAN, RAN, or WAN, odds are its 802.15
- Only 802 Working Group with multiple MAC interfaces

IEEE 802.15 Completed Projects

- 802.15.1- Bluetooth
- 802.15.2- Coexistence Recommended Practice
- 802.15.3- High Rate (55 Mbps) Multimedia WPAN
- 802.15.3c- High Rate (>1Gbps) mmWave 15.3 PHY
- 802.15.4- Low Rate (250kbps) WPAN
- 802.15.4a- Higher data rate 15.4 PHY
- 802.15.4c- Sub 1 GHz 15.4 PHY for China
- 802.15.4d- Sub 1 GHz 15.4 PHY for Japan
- 802.15.5- Mesh Networking Recommended Practice

IEEE 802.15 Completed Projects

- 802.15.4e- 15.4 MAC Enhancements
- 802.15.4f- 15.4 PHY for Active RFID
- 802.15.4g- 15.4 PHY for Smart Utility Networks
- 802.15.4h- 15.4 Corrigendum 1
- 802.15.4i- 15.4 Roll-up to include 15.4a,c & d
- 802.15.4j- 15.4 PHY US dedicated medical band
- 802.15.4k- 15.4 PHY for Low Energy Critical Infrastructure Monitoring
- 802.15.6- Body Area Networking
- 802.15.7- Visible Light Communications

IEEE 802.15 Active Projects

- 802.15.4m- 15.4 PHY utilizing TV White Spaces
- 802.15.4n- 15.4 PHY for CN Medical Applications
- 802.15.4p- 15.4 PHY for Rail Communications & Control
- 802.15.4q- Ultra Low Power 15.4 PHY
- 802.15.4r- 15.4 Roll up for e, f, g, j, and k
- 802.15.8- New standard for Peer Aware Communications
- 802.15.9- Recommended Practice for a Key Management Protocol
- 802.15.10- Recommended Practice for Layer 2 Routing

802.15 MACs

- Low Rate WPAN:
  - 802.15.4-2011 Section 5.2
  - Maximum frame size of 127 bytes!
  - Uses 64-bit or allocated 16-bit MAC addresses that can sometimes be omitted
- Other 802.15.1 (Bluetooth) / 802.15.3 (High Rate) use 8-bit assigned device IDs within local piconets

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References

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  - WG home page http://www.ieee802.org/11/
  - Wi-Fi Alliance http://www.wi-fi.org
- IEEE 802.15
  - WG home page http://www.ieee802.org/15/
  - Bluetooth SIG: http://www.bluetooth.org
  - ZigBee Alliance: http://www.zigbee.org
- Documents for 802 Wireless WGs
  - https://mentor.ieee.org/802/bp/StartPage

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- Some slides taken from Bruce Kraemer, Chair of IEEE 802.11, and Bob Heile, Chair of IEEE 802.15.
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END

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Back up slides

Mesh Support

- 802.11 (Wi-Fi)
  - Wireless Local Area Networks (WLAN, ≤ 100 meters)
  - 802.11s: Mesh Networking
- 802.15 (Blue Tooth, Zigbee, and high rate)
  - Wireless Personal Area Networks (WPAN, originally ≤ 10 meters)
  - More mesh-like from the start
  - 802.15.5 Best Practices for mesh across 802.15.1, 802.15.3, and 802.15.4
  - 802.15.10 Recommended Practice for Layer 2 Routing
- 802.16 (Wi-Max)
  - Wireless Metropolitan Area Networks (WMAN)
  - 802.16j: “multi-hop relay”

Wi-Fi Mobility

- Wi-Fi has always supported “pedestrian” speed mobility
- 802.11r – Rapid roaming, to overcome the set-up overhead of QoS and Security for End Station – AP connections
- 802.11p – Wireless Access in the Vehicular Environment, up to 200 kph relative velocity