Wireless Local Area Networks (WLANs) and Wireless Sensor Networks (WSNs) Primer

Wireless Local Area Networks (WLANs)

- The proliferation of laptop computers and other mobile devices (PDAs and cell phones) created an *obvious* application level demand for wireless local area networking.
- Companies jumped in, quickly developing *incompatible* wireless products in the 1990's.
- Industry decided to entrust standardization to IEEE committee that dealt with wired LANs
  – ***namely, the IEEE 802 committee!!***

IEEE 802 Standards Working Groups

Number	Topic
802.1	Overview and architecture of LANs
802.2 ↓	Logical link control
802.3 *	Ethernet
802.4 ↓	Token bus (was briefly used in manufacturing plants)
802.5	Token ring (IBM's entry into the LAN world)
802.6 ↓	Dual queue dual bus (early metropolitan area network)
802.7 ↓	Technical advisory group on broadband technologies
802.8 †	Technical advisory group on fiber optic technologies
802.9 ↓	Isochronous LANs (for real-time applications)
802.10 ↓	Virtual LANs and security
802.11 *	Wireless LANs
802.12 ↓	Demand priority (Hewlett-Packard's AnyLAN)
802.13	Unlucky number. Nobody wanted it
802.14 ↓	Cable modems (defunct: an industry consortium got there first)
802.15 *	Personal area networks (Bluetooth) 802.15.4 ZigBee
802.16 *	Broadband wireless
802.17	Resilient packet ring

Figure 1-38. The important ones are marked with *. The ones marked with ↓ are hibernating. The one marked with † gave up.

IEEE 802.11

The following IEEE 802.11 standards exist or are in development to support the creation of technologies for wireless local area networking:

- **802.11a** - 54 Mbps standard, 5 GHz signaling (ratified 1999)
- **802.11b** - 11 Mbps standard, 2.4 GHz signaling (1999)
- **802.11c** - operation of bridge connections (moved to 802.1D)
- **802.11d** - worldwide compliance with regulations for use of wireless signal spectrum (2001)
- **802.11e** - Quality of Service (QoS) support (not yet ratified)
- **802.11f** - Inter-Access Point Protocol recommendation for communication between access points to support roaming clients (2003)
- **802.11g** - 54 Mbps standard, 2.4 GHz signaling (2003)
- **802.11h** - enhanced version of 802.11a to support European regulatory requirements (2003)
- **802.11i**- security improvements for the 802.11 family (2004)
- **802.11j** - enhancements to 5 GHz signaling to support Japan regulatory requirements (2004)
- **802.11k** - WLAN system management (in progress)

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IEEE 802.11

The following IEEE 802.11 standards exist or are in development to support the creation of technologies for wireless local area networking:

- **802.11m** - maintenance of 802.11 family documentation
- **802.11n** - 100+ Mbps standard improvements over 802.11g (in progress)
- **802.11p**- Wireless Access for the Vehicular Environment
- **802.11r** - fast roaming support via Basic Service Set transitions
- **802.11s** - ESS mesh networking for access points
- **802.11t** - Wireless Performance Prediction - recommendation for testing standards and metrics
- **802.11u** - internetworking with 3G / cellular and other forms of external networks
- **802.11v** - wireless network management / device configuration
- **802.11w** - Protected Management Frames security enhancement
- **802.11x**- skipped (generic name for the 802.11 family)
- **802.11y** - Contention Based Protocol for interference avoidance

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Wireless Classification

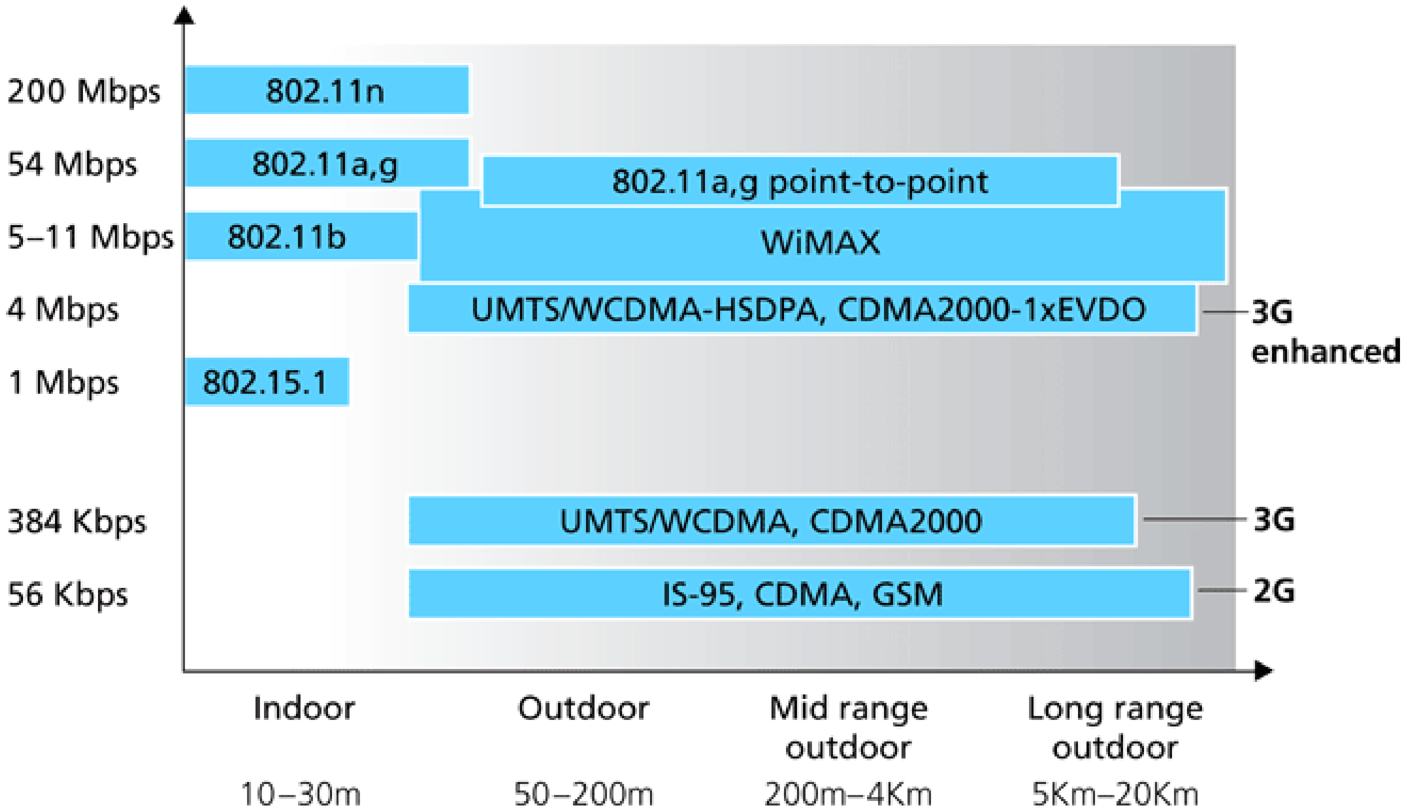

Figure 6.2 ♦ Link characteristics of selected wireless network standards

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Classification of Wireless Networks

- **Base Station** :: all communication through an ***Access Point* (AP)** {note hub topology}. Other nodes can be fixed or mobile.
- **Infrastructure Wireless** :: **AP** is connected to the **wired** Internet.
- Ad Hoc Wireless :: wireless nodes communicate directly with one another.
- **MANETs (Mobile Ad Hoc Networks)** :: ad hoc nodes are mobile.

Wireless LANs

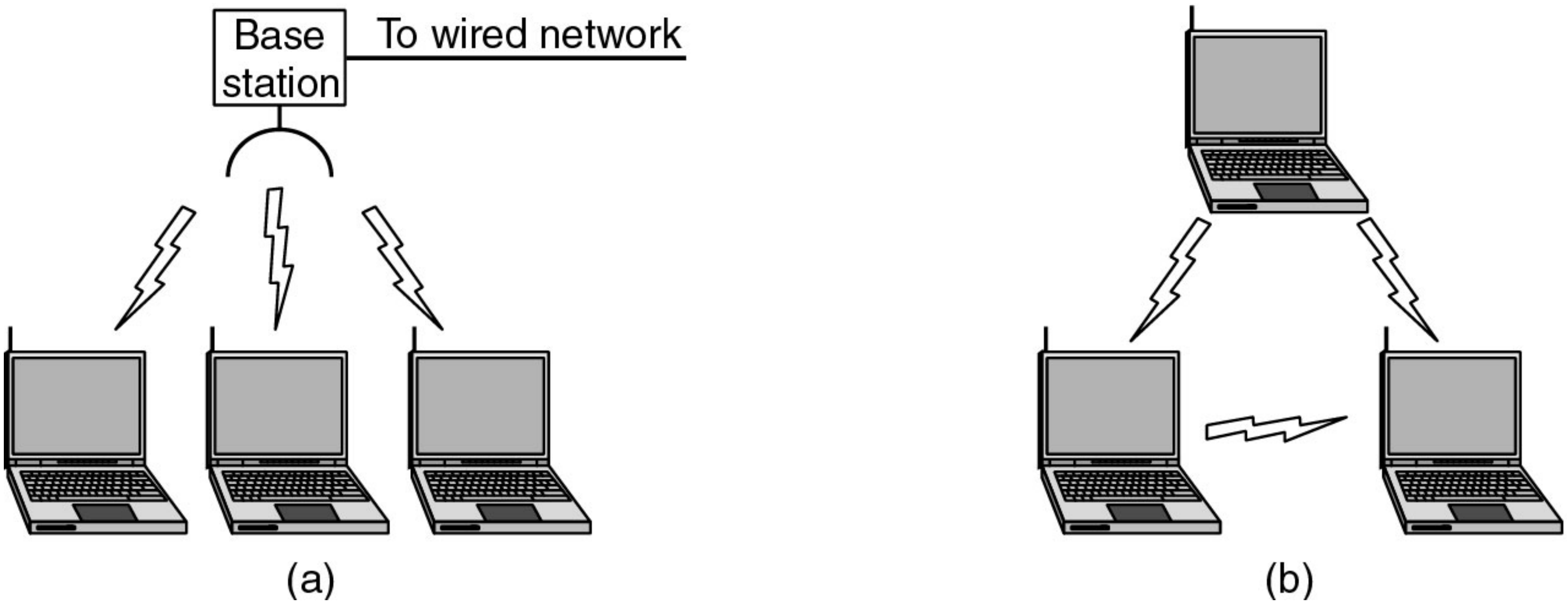


Figure 1-36.(a) Wireless networking with a base station. (b) Ad hoc networking.

The 802.11 Protocol Stack

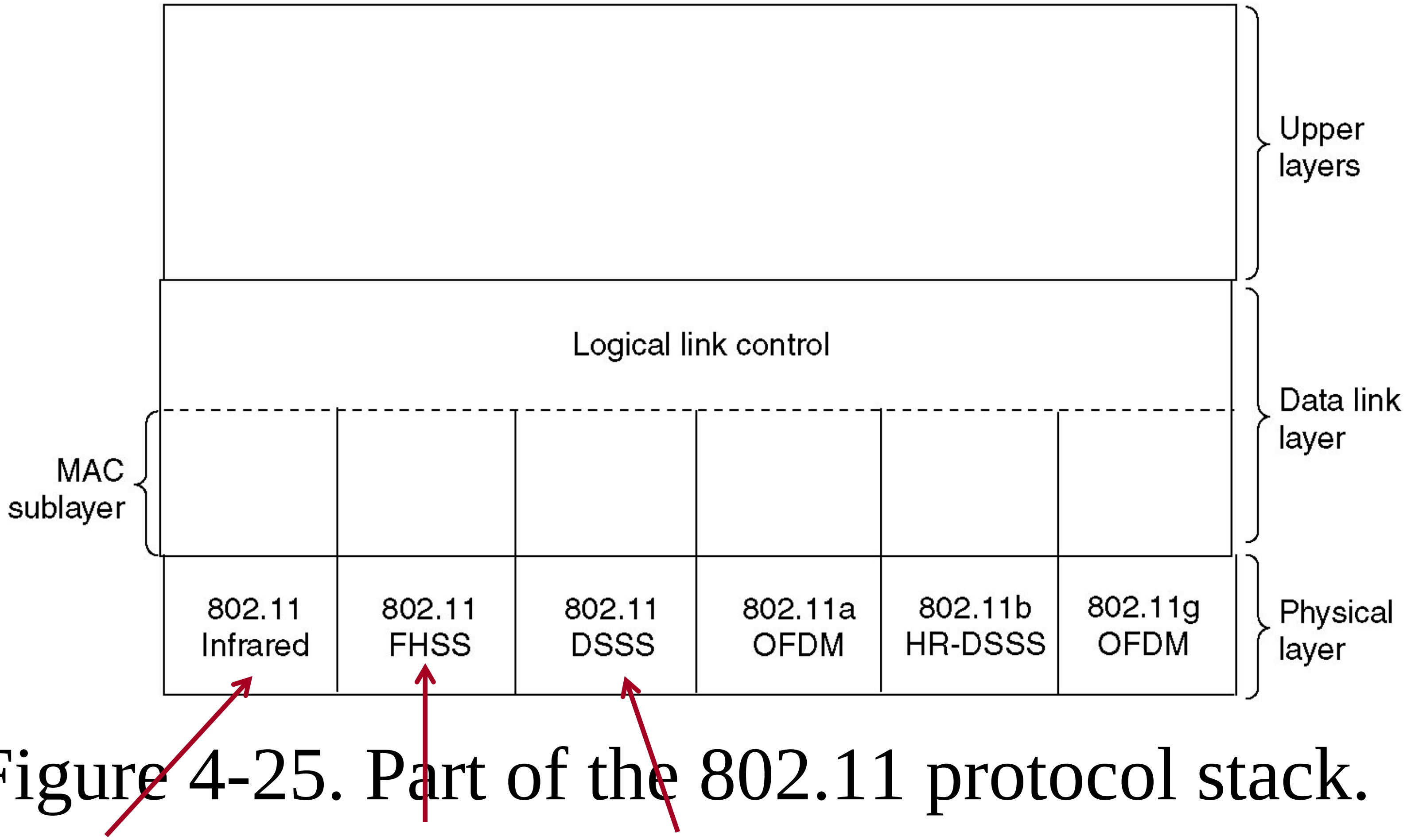


Figure 4-25. Part of the 802.11 protocol stack.

Note – ordinary 802.11 products are no longer being manufactured.

Wireless Physical Layer

- Physical layer conforms to OSI (five options)
  - 1997: **802.11** infrared, FHSS, DSSS {FHSS and DSSS run in the 2.4GHz band}
  - 1999: **802.11a** OFDM and **802.11b** HR-DSSS
  - 2001: **802.11g** OFDM
- **802.11 *Infrared***
  - Two capacities: **1 Mbps** or **2 Mbps**.
  - Range is 10 to 20 meters and cannot penetrate walls.
  - Does not work outdoors.
- **802.11 *FHSS* (*Frequence Hopping Spread Spectrum*)**
  - **The main issue is *multipath fading*.**
  - ***[P&D] The idea behind spread spectrum is to spread the signal over a wider frequency to minimize the interference from other devices.***
  - 79 non-overlapping channels, each 1 Mhz wide at low end of 2.4 GHz ISM band.
  - The same pseudo-random number generator used by all stations to start the hopping process.
  - Dwell time: min. time on channel before hopping (400msec).

Wireless Physical Layer

- **802.11 *DSSS* (*Direct Sequence Spread Spectrum*)**
  - ***The main idea is to represent each bit in the frame by multiple bits in the transmitted signal (i.e., it sends the XOR of that bit and n random bits).***
  - Spreads signal over entire spectrum using pseudo-random sequence (similar to **CDMA** see Tanenbaum sec. 2.6.2).
  - Each bit transmitted using an 11-bit chipping Barker sequence, PSK at 1Mbaud.
  - This yields a capacity of 1 or 2 Mbps.

unique code per sender

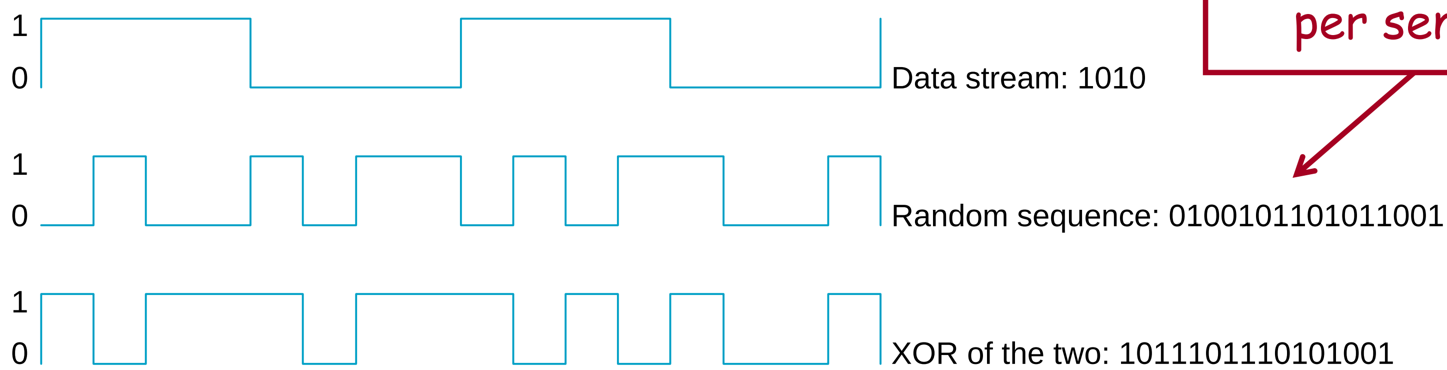
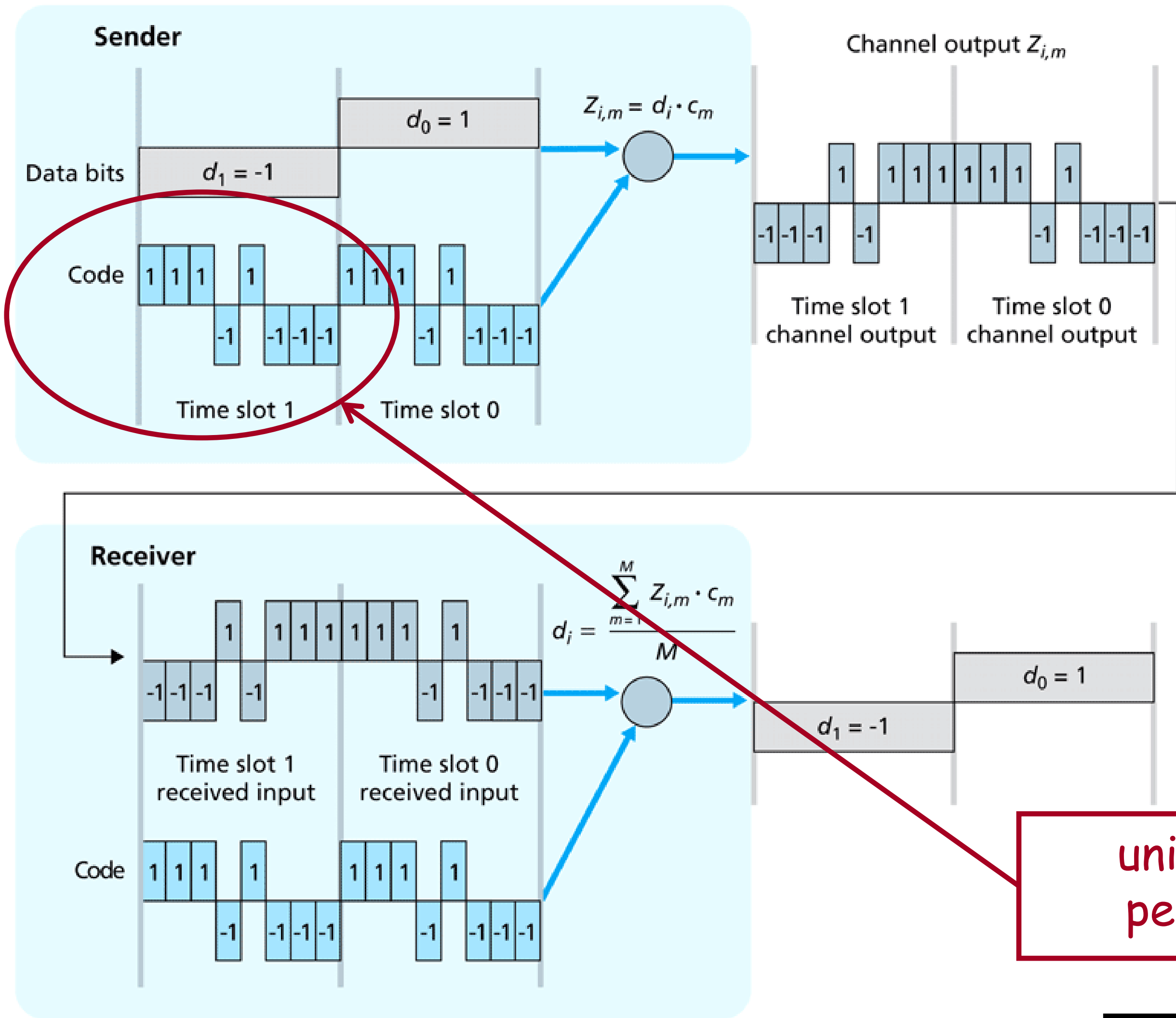


Figure 2.37 Example 4-bit chipping sequence

P&D slide



unique code per sender

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Figure 6.5 ♦ A simple CDMA example: sender encoding, receiver decoding

Wireless Physical Layer

- **802.11a *OFDM* (Orthogonal Frequency Divisional Multiplexing)**
  - Compatible with European HiperLan2.
  - **54 Mbps** in wider 5.5 GHz band ➔ transmission range is limited.
  - Uses 52 FDM channels (48 for data; 4 for synchronization).
  - Encoding is complex (PSM up to 18 Mbps and QAM above this capacity).
  - E.g., at 54 Mbps 216 data bits encoded into into 288-bit symbols.
  - More difficulty penetrating walls.

Wireless Physical Layer

- **802.11b *HR-DSSS* (*High Rate Direct Sequence Spread Spectrum*)**
  - **11a and 11b** *shows a split in the standards committee.*
  - **11b** approved and hit the market before **11a.**
  - Up to **11 Mbps** in 2.4 GHz band using 11 million chips/sec.
  - Note in this bandwidth all these protocols have to deal with interference from microwave ovens, cordless phones and garage door openers.
  - Range is 7 times greater than **11a.**
  - **11b and 11a are incompatible!!**

Wireless Physical Layer

- 802.11g *OFDM(Orthogonal Frequency Division Multiplexing)*
  - **An attempt to combine the best of both 802.11a and 802.11b.**
  - Supports bandwidths up to **54 Mbps**.
  - Uses 2.4 GHz frequency for greater range.
  - Is backward compatible with 802.11b.

802.11 MAC Sublayer Protocol

- In 802.11 wireless LANs, “seizing the channel” does not exist as in 802.3 wired Ethernet.
- Two additional problems:
  - Hidden Terminal Problem
  - Exposed Station Problem
- To deal with these two problems 802.11 supports two modes of operation:
  - **DCF (Distributed Coordination Function)**
  - **PCF (Point Coordination Function).**
- **All implementations must support DCF, but PCF is optional.**

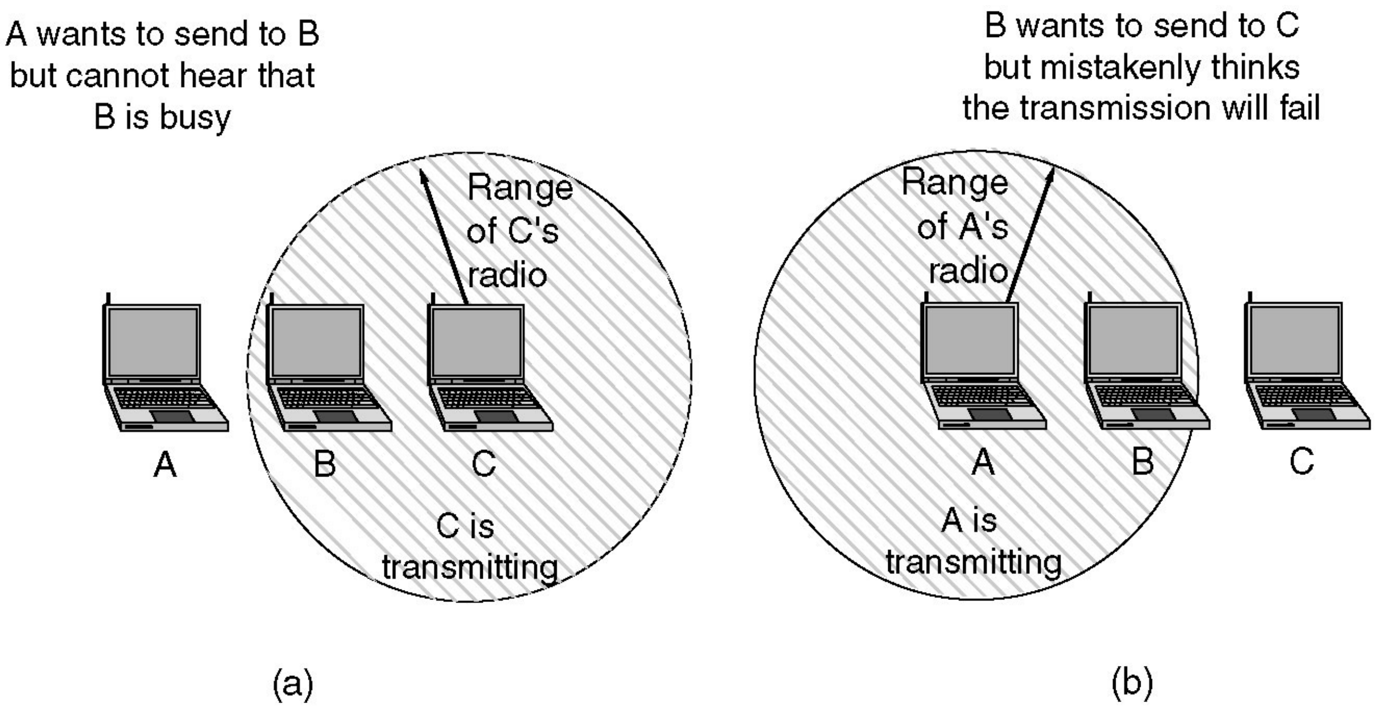


Figure 4-26.(a)The hidden terminal problem. (b) The exposed station problem.

The Hidden Terminal Problem

- Wireless stations have transmission ranges and not all stations are within radio range of each other.
- Simple CSMA will not work!
- C transmits to B.
- If A "**senses**" the channel, it will not hear C's transmission and falsely conclude that A can begin a transmission to B.

The Exposed Station Problem

- This is the inverse problem.
- B wants to send to C and listens to the channel.
- When B hears A's transmission, B falsely assumes that it cannot send to C.

Distribute Coordination Function (DCF)

- Uses *CSMA/CA* (*CSMA* with *C*ollision *A*voidance).
  - Uses one of two modes of operation:
    - ***virtual carrier sensing***
    - physical carrier sensing
- The two methods are supported:

1. ***MACAW* (Multiple Access with Collision Avoidance for Wireless) with virtual carrier sensing.**
2. **1-persistent physical carrier sensing.**

Wireless LAN Protocols
[Tan pp.269-270]

- *MACA* protocol solved hidden and exposed terminal problems:
  - Sender broadcasts a Request-to-Send (***RTS***) and the intended receiver sends a Clear-to-Send (***CTS***).
  - Upon receipt of a ***CTS,*** the sender begins transmission of the frame.
  - RTS, CTS helps determine who else is in range or busy (***C***ollision ***A***voidance).
  - Can a collision still occur?

Wireless LAN Protocols

- ***MACAW*** added ACKs, Carrier Sense, and BEB done per stream and **not** per station.

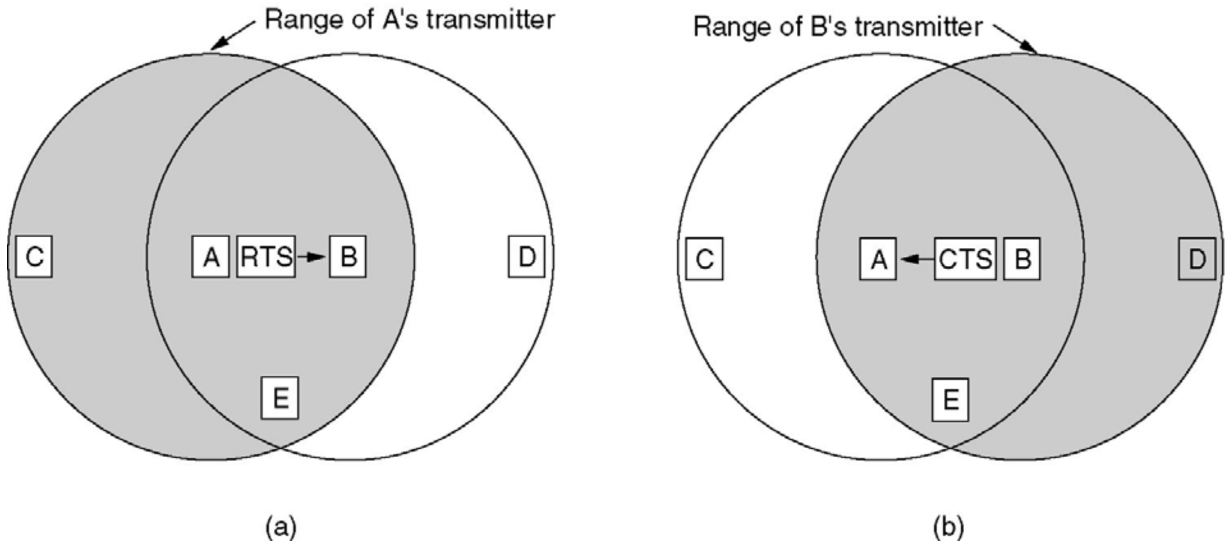


Figure 4-12. (a) A sending an RTS to B.
(b) B responding with a CTS to A.

Virtual Channel Sensing in CSMA/CA

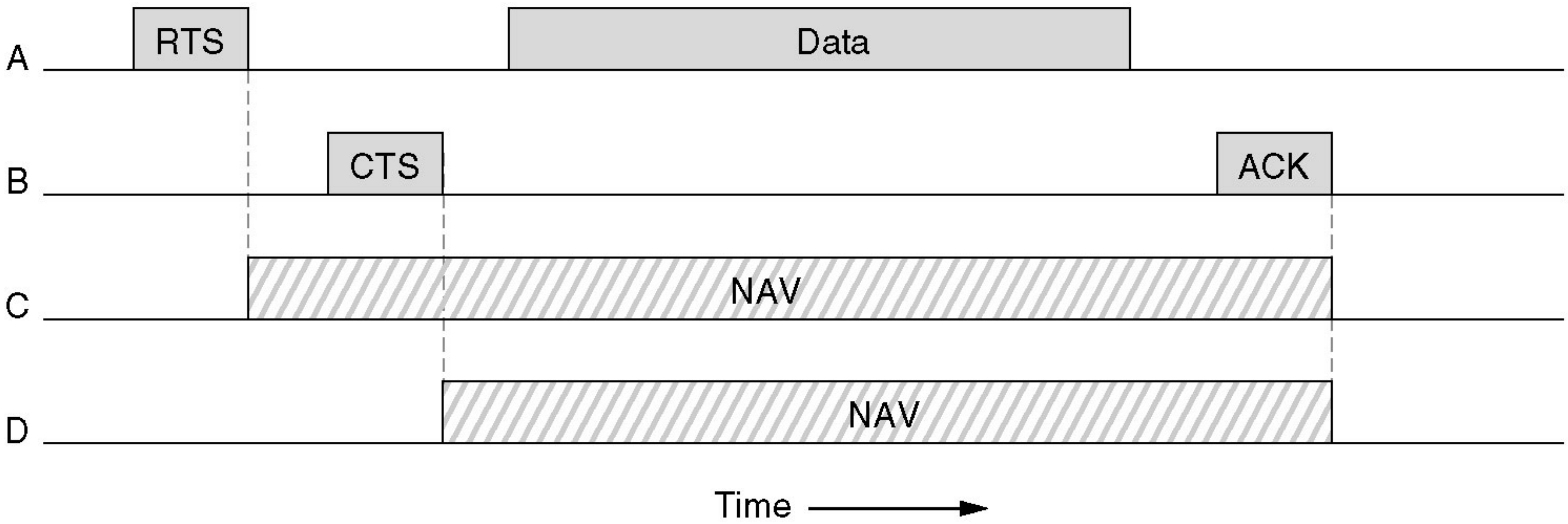


Figure 4-27. The use of virtual channel sensing using CSMA/CA.

- C (in range of A) *receives the RTS and based on information in RTS creates a* ***virtual channel busy*** **NAV(Network Allocation Vector).**
- D (in range of B) *receives the CTS and creates a shorter* **NAV.**

Virtual Channel Sensing in CSMA/CA

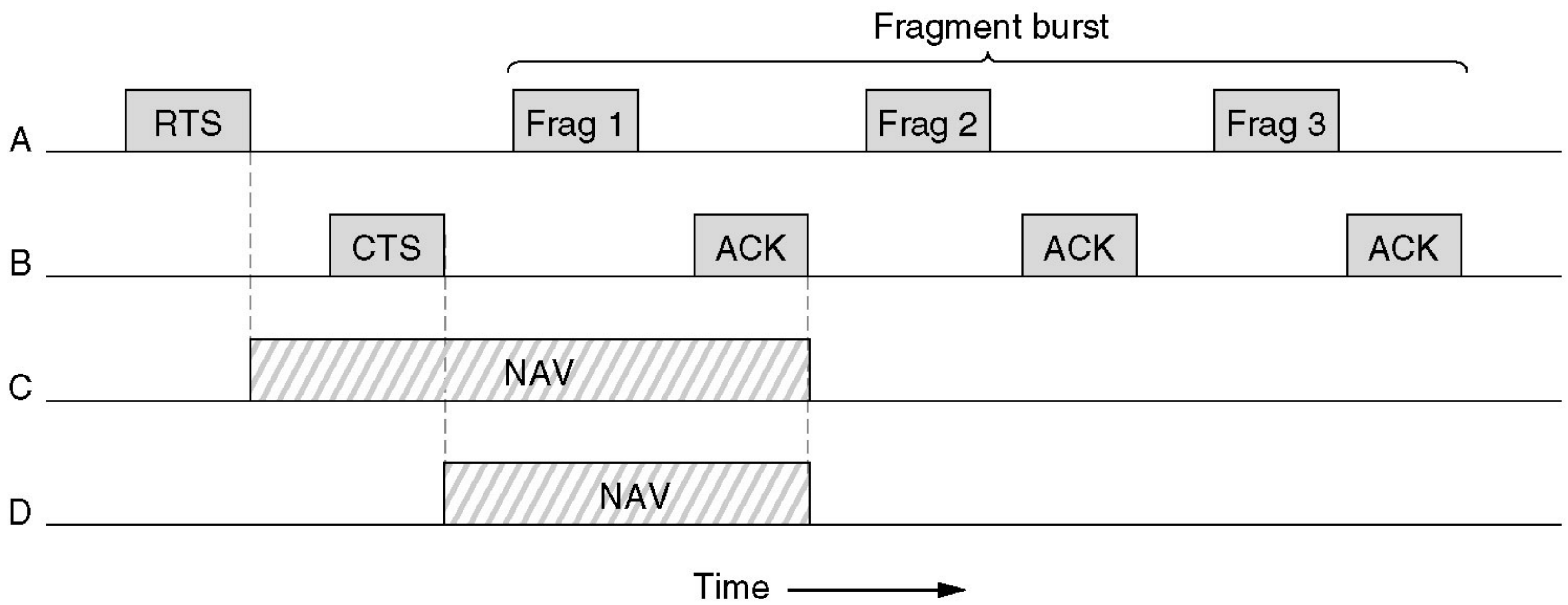
What is the advantage of RTS/CTS?

RTS is 20 bytes, and CTS is 14 bytes.

MPDU can be 2300 bytes.

- "virtual" implies source station sets the *duration field* in data frame or in RTS and CTS frames.
- Stations then adjust their NAV accordingly!

Figure 4-28 Fragmentation in 802.11



- High wireless error rates → long packets have less probability of being successfully transmitted.
- Solution: MAC layer fragmentation with stop-and-wait protocol on the fragments.

1-Persistent Physical Carrier Sensing

- The station senses the channel when it wants to send.
- If idle, the station transmits.
  - *A station does not sense the channel while transmitting.*
- If the channel is busy, the station defers until idle and then transmits (1-persistent).
- Upon collision, wait a *random time* using binary exponential backoff (BEB).

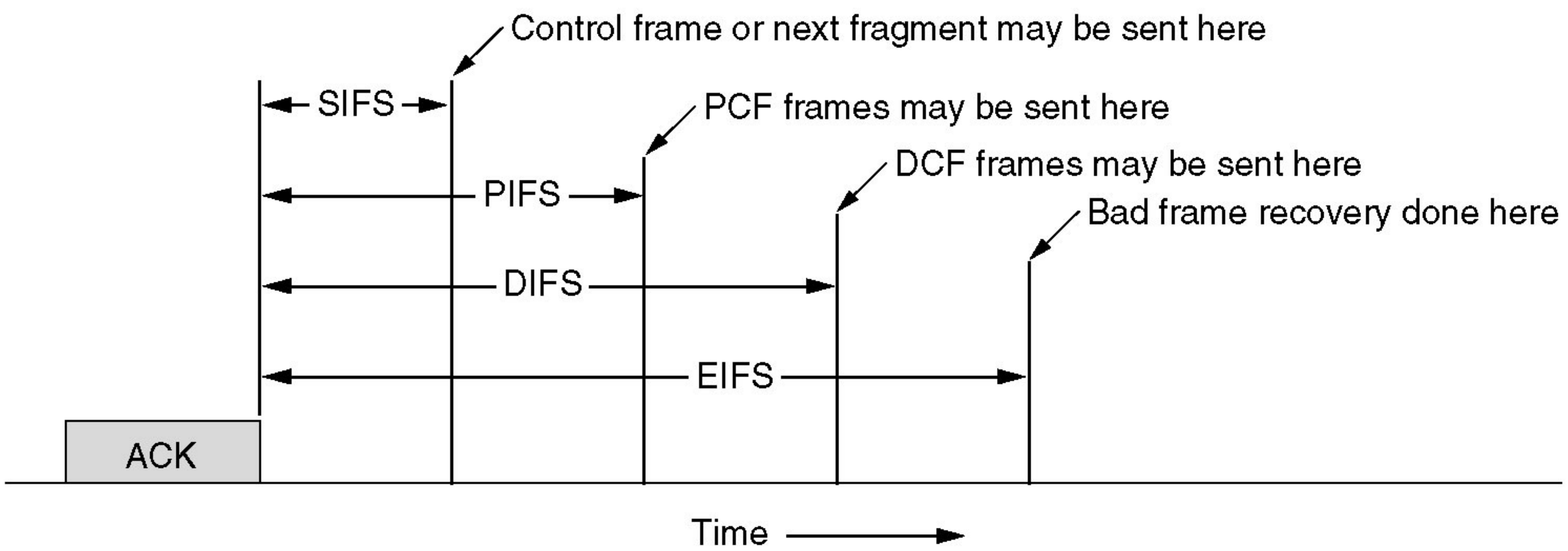
Point Coordinated Function (PCF)

- PCF uses a base station to poll other stations to see if they have frames to send.
- No collisions occur.
- Base station sends **beacon frame** periodically.
- Base station can tell another station to **sleep** to save on batteries and base stations holds frames for sleeping station.

DCF and PCF Co-Existence

- Distributed and centralized control can co-exist using InterFrame Spacing.
- SIFS (Short IFS) :: is the time waited between packets in an ongoing dialog (RTS,CTS,data, ACK, next frame)
- PIFS (PCF IFS) :: when no SIFS response, base station can issue beacon or poll.
- DIFS (DCF IFS) :: when no PIFS, any station can attempt to acquire the channel.
- EIFS (Extended IFS) :: lowest priority interval used to report bad or unknown frame.

Figure 4-29. Interframe Spacing in 802.11.



Basic CSMA/CA

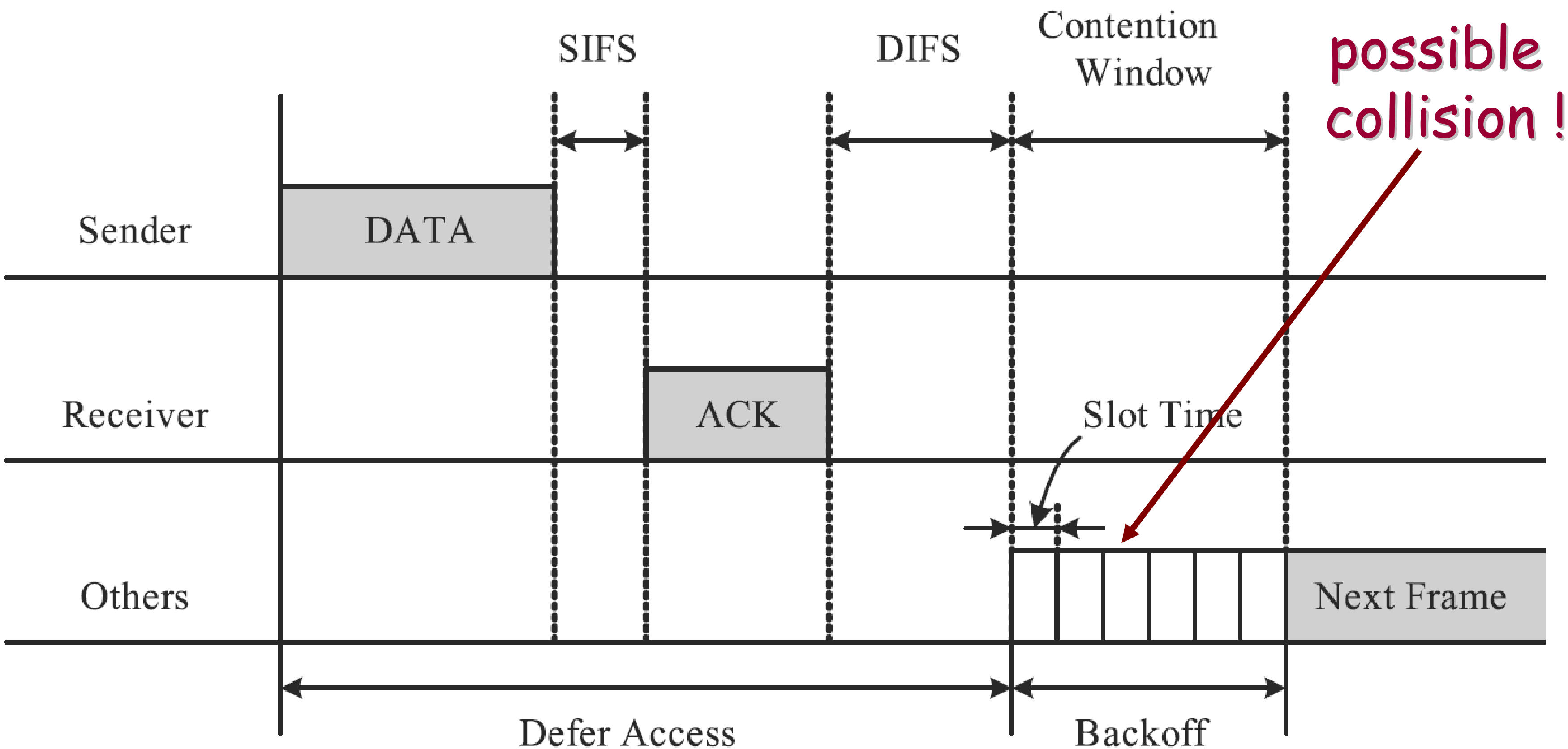


Fig. 1 CSMA/CA protocol of IEEE 802.11 MAC DCF. [N. Kim]

A Few Wireless Details

- 802.11b and 802.11g use **dynamic rate adaptation** based on frame loss (algorithms internal to wireless card at the AP)
  - e.g. for 802.11b choices are: 11, 5.5, 2 and 1 Mbps
- Standard 802.11 retries
  - 7 retries for RTS and CTS
  - 4 retries for Data and Ack frames
- RTS/CTS may be turned off by default [Research has shown that RTS/CTS degrades performance when hidden terminal is not an issue].

A Few Wireless Details

- All APs (or base stations) will periodically send a beacon frame (10 to 100 times a second).
- Beacon frames are also used by DCF to synchronize and handle nodes that want to **sleep.** The AP will buffer frames intended for a sleeping wireless client.
- AP downstream/upstream traffic performance is **asymmetric**.
- Wireless communication quality between two nodes can be asymmetric due to **multipath fading**.

Node Contention

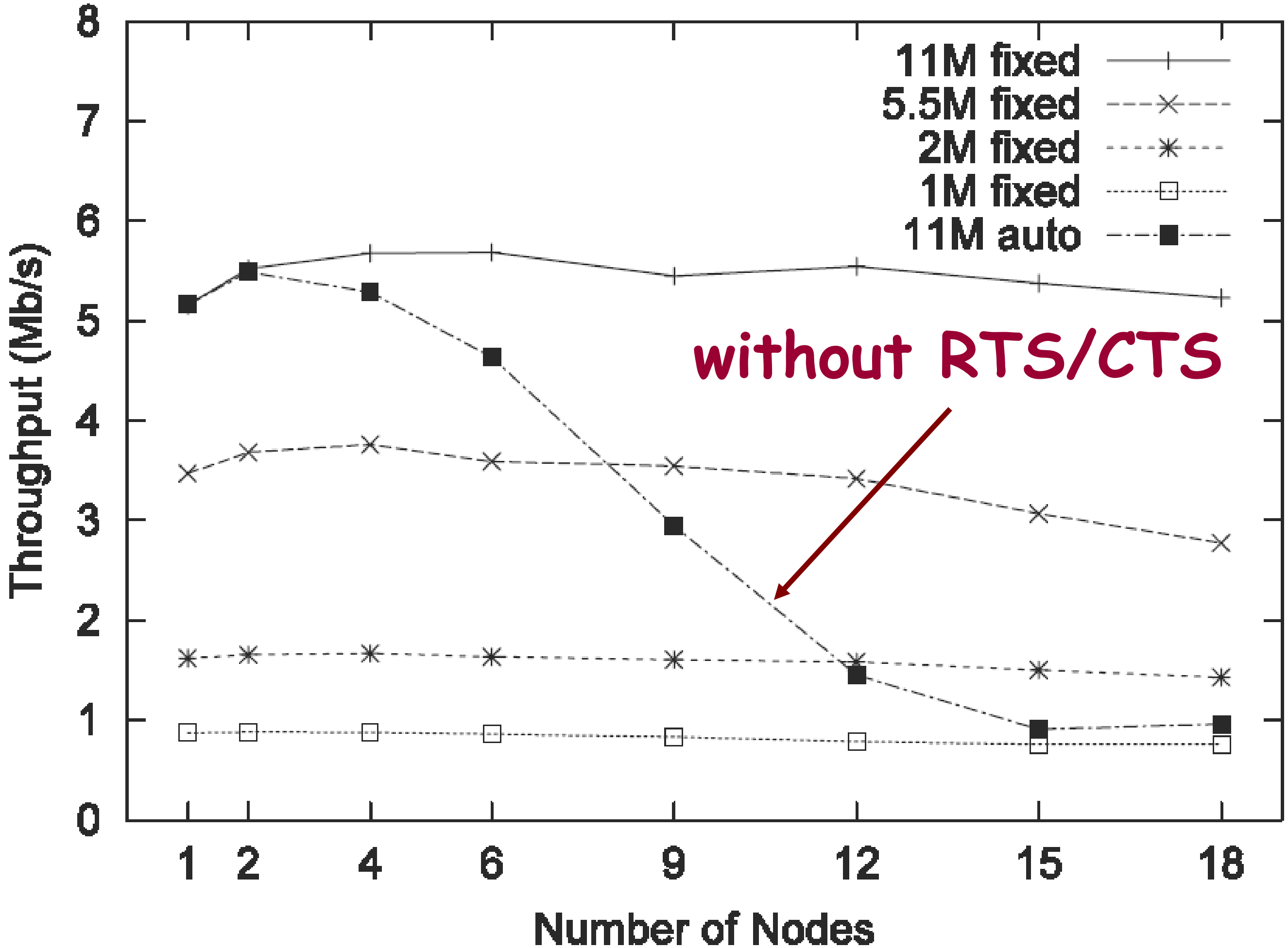


Fig. 7 Throughputs with node contentions.

[N. Kim]

Rate Adaptation versus Distance

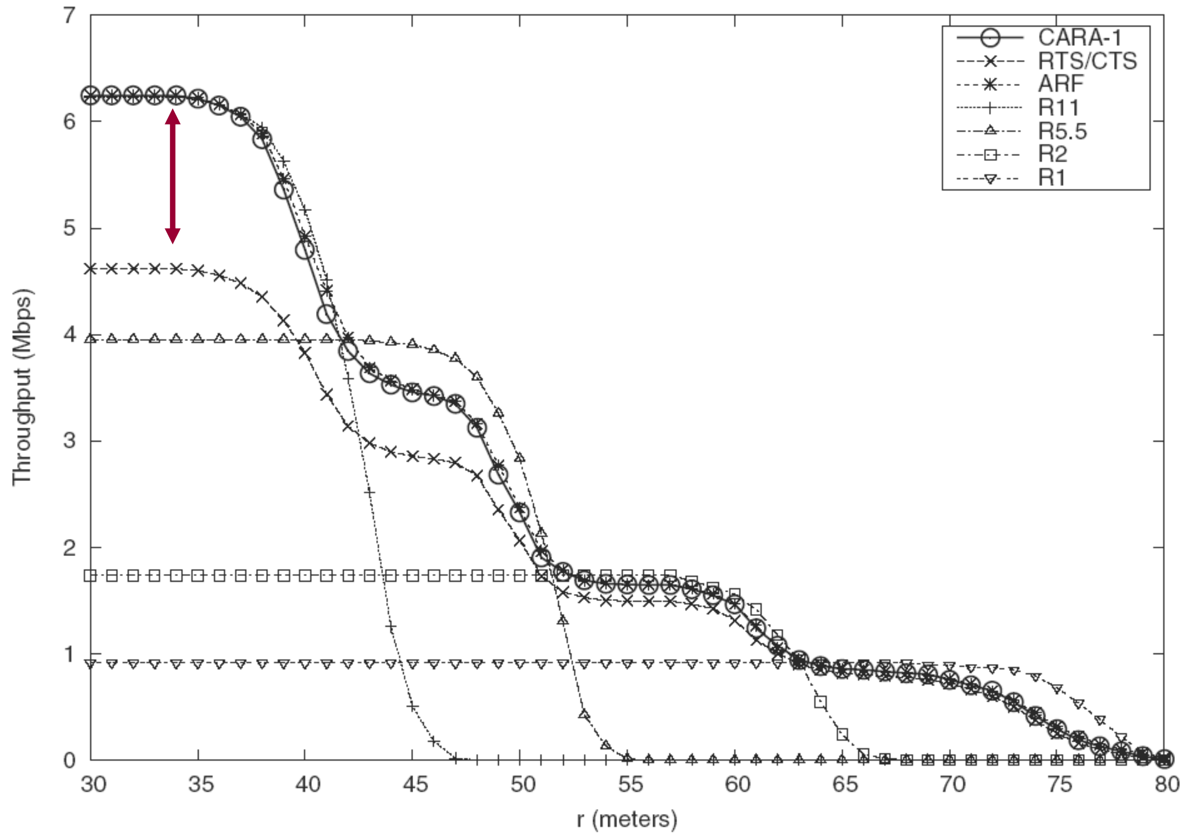


Fig. 6. Throughput comparison of our proposed rate adaptation scheme (CARA-1) against RTS/CTS, ARF, and single-rate schemes for one-to-one topology networks with various distance (r)

[CARA paper]

Dynamic Rate Adaptation

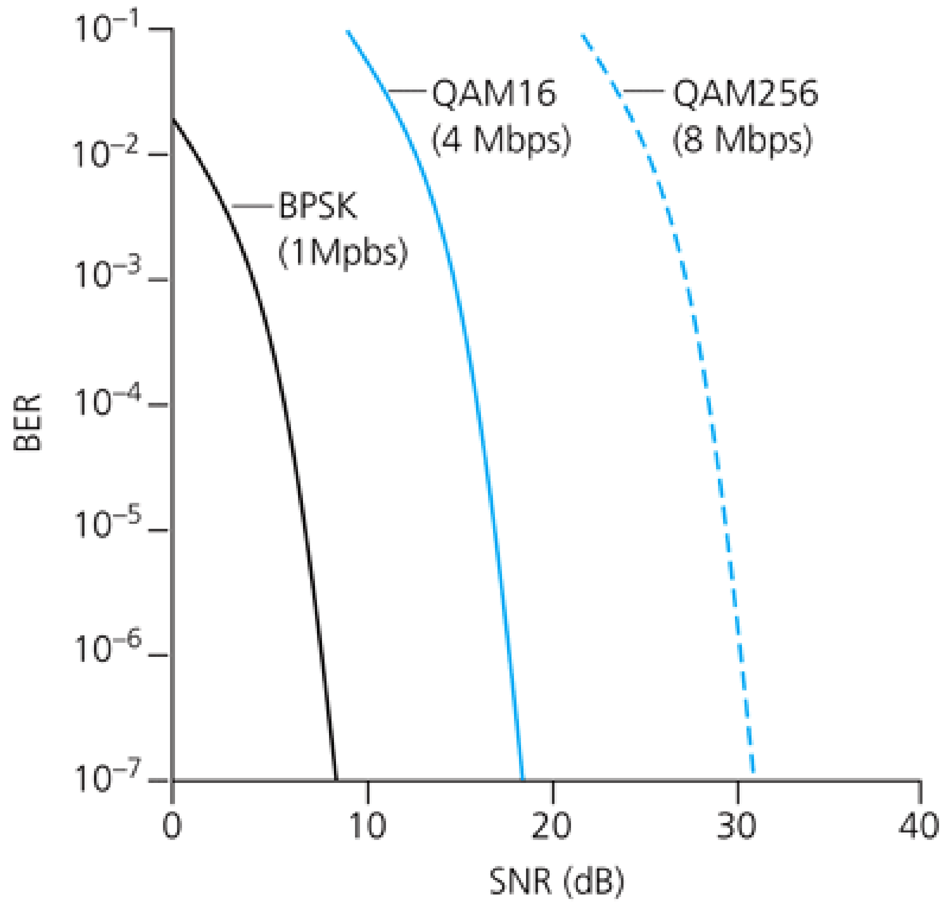


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Figure 6.3 ♦ Bit error rate, transmission rate, and SNR

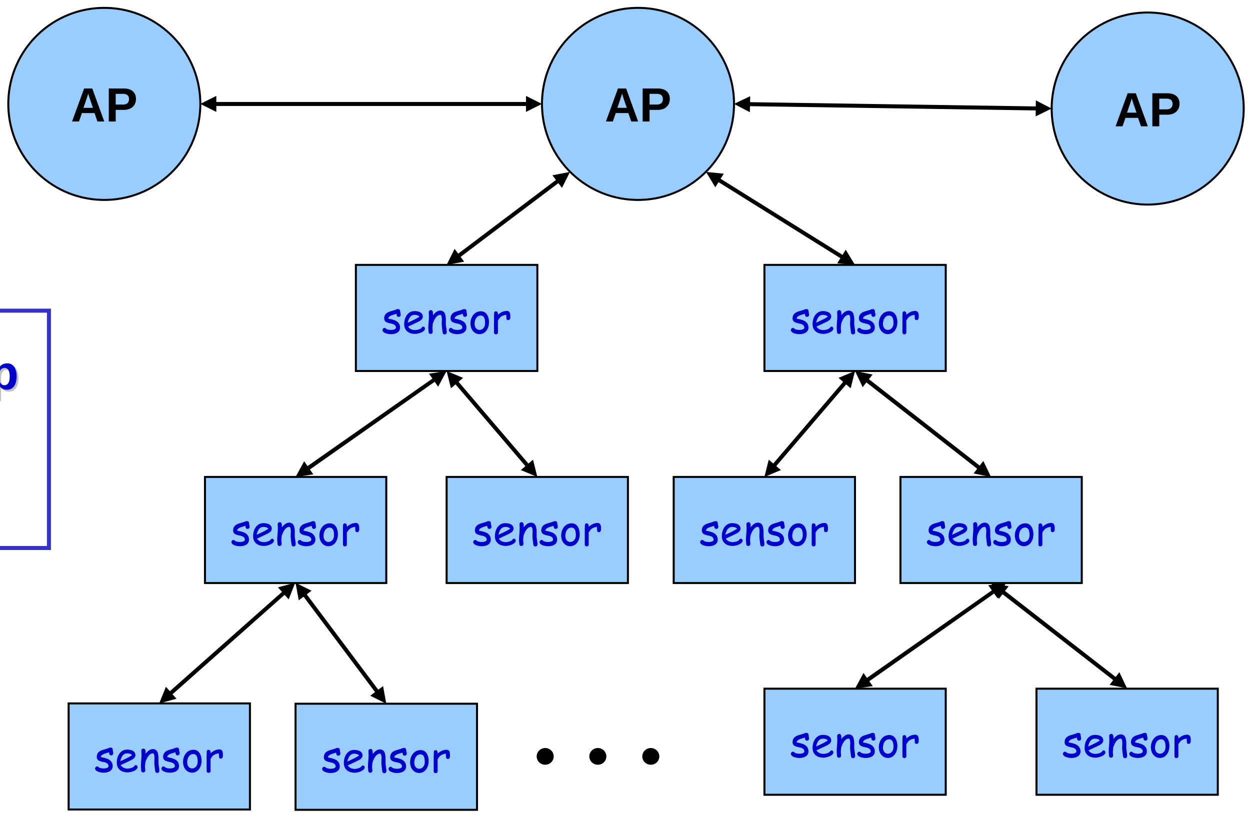
Wireless Sensor Networks

- Sensors – small devices with low-power transmissions and energy limitations (e.g., battery lifetime is often a **BIG** concern.)
- The main distinction from traditional wireless networks is that the data traffic originates at the sensor node and is sent **upstream** towards the access point (AP) or base station that collects the data.
- While the nature of data collection at the sensor is likely to be **event driven**, for robustness, the generation of sensor packets should be ***periodic*** if possible.

Tiered Architecture

- Smaller sensors on the leaves of the tree
  1. Motes, TinyOS
  2. Strong ARM PDA running Linux
  - Battery powered, lifetime is critical.
  - Need to be able to adjust transmission power and permit sensor to go to sleep.
- Second Tier
  - AP, base station or video aggregator
  - Data sent from sensors to more powerful computers for storage and analysis.

The Berkeley System



Multiple hop tree topology

The Berkeley System