

The MAC layer in wireless networks

- The **wireless** MAC layer roles
 - **Access control to shared channel(s)**
 - **Natural broadcast** of wireless transmission
 - **Collision of signal: a time/space problem**
 - **Who transmits when? (and where)?**
 - **Avoid collisions (no Collision Detection)**
 - **Scarce resources utilization**
 - **Channel capacity and battery power**
 - **performance and QoS**
 - **System level and (or vs?) user level**
 - **Frame organization, and intra-, inter-layer information management**
 - **Cross layering principles for adaptive behavior?**
 - **Risk for "spaghetti design" [Kumar2003]**

[Kumar2003] V. Kawadia, P.R. Kumar, "A Cautionary Perspective on Cross Layer Design", Submitted for publication, 2003 (<http://black1.csl.uiuc.edu/~prkumar/>)

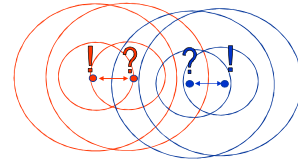
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Collision of wireless signals

- **Collision** has **destructive effect on the receiver**
 - ...causes both channel and power waste
 - Collision detection is not practical in wireless systems
 - Collision avoidance/resolution + contention control on the sender
- Capture effect is possible
 - Exploited to enhance channel reuse, if possible
- Collision domain: set of nodes sharing the same channel
 - Space splitting, transitive relation

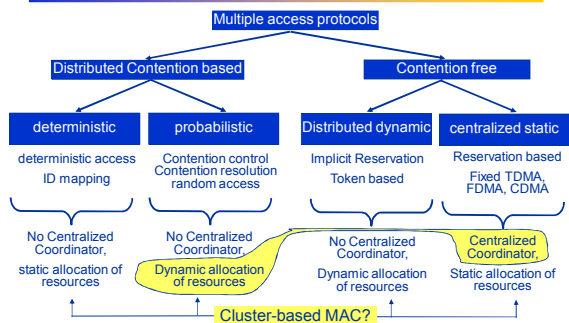


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Wireless MAC protocols' classification



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Evolutionary perspective of distributed MAC

- Distributed, contention-based wireless MAC Problem:
 - the frame vulnerability (collision risk)
 - Needs resolution in distributed way (no centralized coordinator)
- let's analyze the **time domain first**
 - Aloha [Abramson1970]: no coordination
 - Slotted Aloha
 - CSMA [Kleinrock1975]: listen before to transmit
 - Slotted CSMA
 - CSMA/CD: listen before and while transmitting
 - (unpractical in wireless scenarios)
 - CSMA/CA + contention resolution (reactive resolution of collisions)
 - CSMA/CA + contention control (preventive/reactive reduction of risk of collisions)

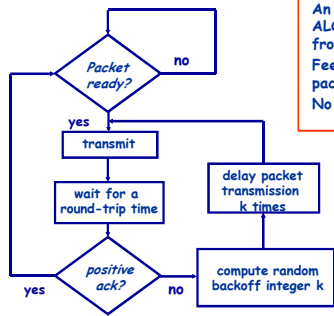
[Abramson1970] N. Abramson, "The ALQHA system - another alternative for computer communications", Proc. Fall Joint Comput. Conf. AFPS, 1970
 [Kleinrock1975] Kleinrock, F.A. Tobagi, "Packet Switching in Radio Channels: Part I - Carrier Sense Multiple-Access modes and their throughput-delay characteristics", IEEE Transactions on Communications, Vol. Com-23, No. 12, pp.1400-1416, 1975

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The ALOHA protocol



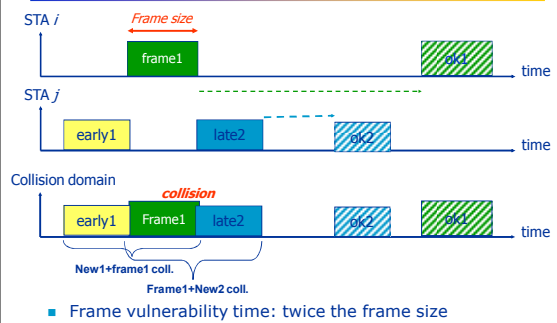
An integral part of the ALOHA protocol is feedback from the receiver
 Feedback occurs *after* a packet is sent
 No coordination among sources

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The ALOHA protocol

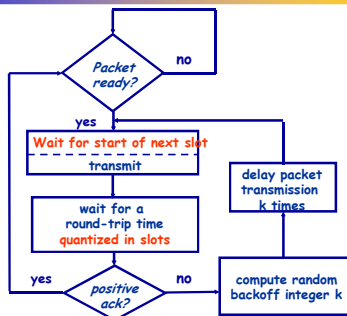


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Slotted ALOHA

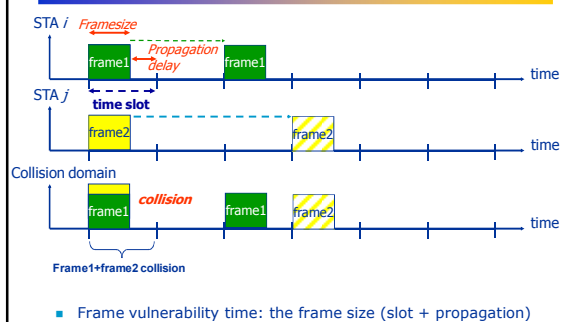


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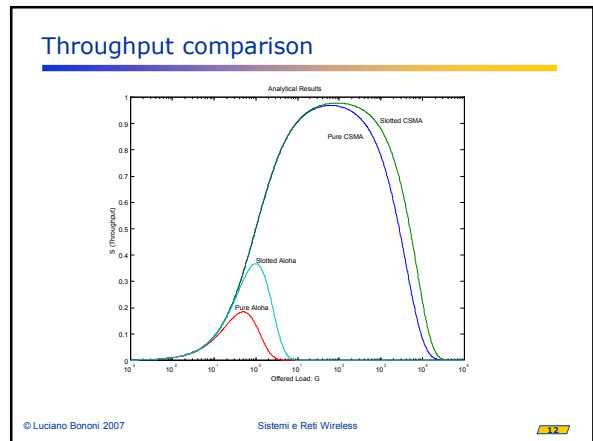
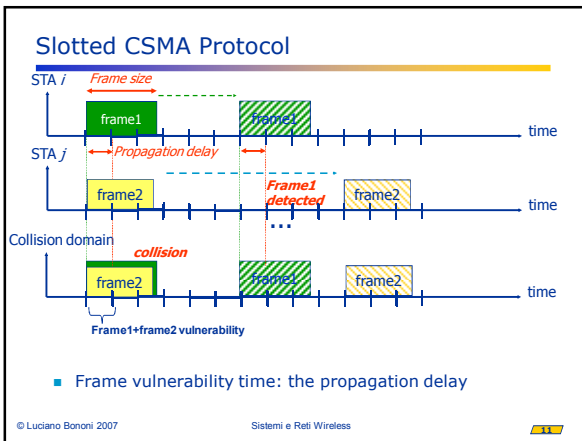
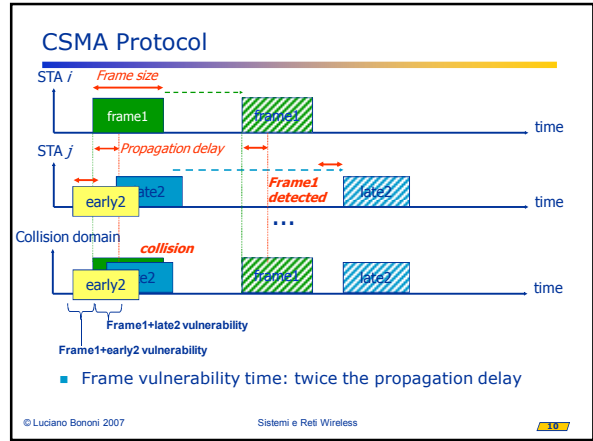
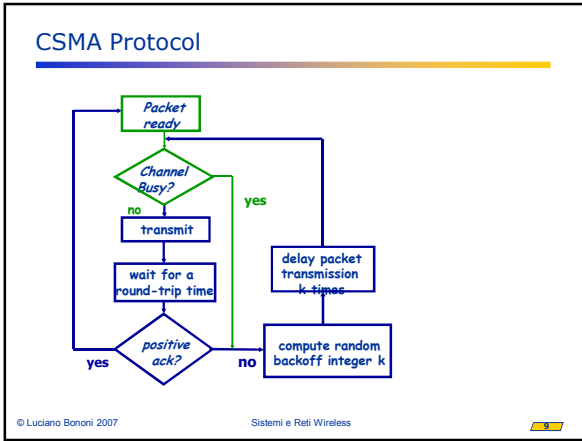
Slotted ALOHA



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CSMA/CA: the IEEE 802.11 Wireless LAN

- **1 Medium Access Control (MAC) protocol:**
 - 2 coordination functions co-exist in a superframe structure (time division)
 - **Distributed Coordination Function (DCF)**
 - Ad-Hoc networks (peer to peer)
 - Distributed control (no base station)
 - contention based access (no QoS, no minimum delay)
 - CSMA/CA access protocol with Binary Exponential Backoff
 - **Point Coordination Function (PCF)**
 - Centralized control (Base station)
 - Polling based access (soft QoS, minimum delay)
 - minimum bandwidth guarantee

Will be analyzed later...

Evolutionary perspective of distributed MAC

- Distributed, contention-based wireless MAC Problem:
 - the frame vulnerability (collision risk)
 - Needs resolution in distributed way (no centralized coordinator)
- let's analyze the **Space domain**
 - MACA [Karn1990]: RTS/CTS, no carrier sense (MACA-BI, RIMA...)
 - MACAW [Bharghavan et al.1994]: RTS/CTS, no carrier sense and immediate ACK (more reliable and efficient Link Layer Control)
 - FAMA [Fullmer et al.1995]: RTS/CTS, carrier sense + other stuff
- Main solution: RTS/CTS mechanism
 - Today under some criticisms

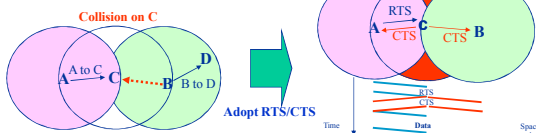
[Karn1990]
P. Karn, "MACA - A new Channel Access Method for Packet Radio", proc. 9-th Computer Networking Conference, September 1990

[Bharghavan et al. 1994]
V. Bharghavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A Media Access Protocol for Wireless LAN's," proc. ACM SIGCOMM'94, pp.212-225, London, 1994

[Fullmer et al. 1995]
D.L. Fullmer, J.J. Garcia-Luna-Aceves, "Floor Acquisition Multiple Access (FAMA) for Packet Radio Networks", Proc. ACM Sigcomm'95 Cambridge, MA, 1995

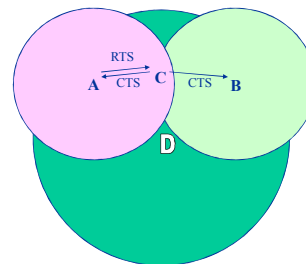
Hidden and Exposed terminals: RTS/CTS

- **The space domain:**
- Hidden and exposed terminals: space vulnerability
- RTS/CTS mechanism to contrast Hidden terminals
 - Hidden terminals: B does not sense traffic, but the receiver C cannot receive its packet due to a transmission from A to C (A hidden to B)
 - to seize the channel, according to CSMA/CA, a station transmits a short RTS (request to send) packet and waits for the CTS (Clear to Send) response.
 - A transmit RTS to C and seizes the coverage area
 - C respond with CTS to A (B receive the CTS and does not transmit even if it cannot sense A's transmission)



RTS/CTS drawbacks

- **RTS/CTS is not a "guaranteed" solution and it is additional overhead**
- Power asymmetry, detection and interference range >> transmission range



Ad hoc Multi-hop: Time/Space problems

- A bi-directional chain of MAC frames
 - TCP streams (Data + Ack)
- Self-contention (MAC layer problem)
 - Inter-stream self-contention (Data vs. Ack TCP streams)
 - Intra-stream self-contention (same TCP stream)
 - How to obtain coordination?
 - New proposed solutions
 - Fast forward
 - Quick exchange
 - Flow numbering (pre-routing at the MAC layer???)
 - Frame transmission by forward invitation

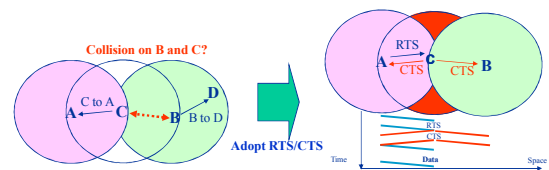
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MACA: slotted RTS/CTS, no CS

- MACA: **eliminates the carrier sensing**
 - ...because the contention is on the receiver!
- Introduces **slotted RTS/CTS** (30 bytes each) and slot time equals the RTS (and CTS) duration
- Allow exploitation of concurrent spatial transmission if the receiver is not exposed to two hidden transmitter terminals
- Variations: MACA-BI, RIMA (receiver initiated)



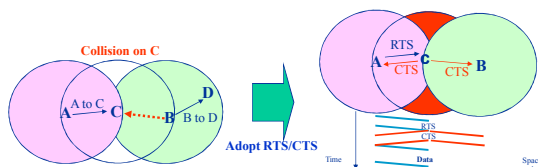
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MACAW: no cs + slotted RTS/CTS + ACK

- MACAW: fairness of the backoff procedure
 - MILD + Binary Exponential Backoff
 - Cooperation-based backoff values (space-issues of contention)
- no carrier sensing before both slotted RTS/CTS
- Introduces ACK (RTS - CTS - DATA - ACK)
 - Efficient retransmission policy at Data Link layer
- Problem: both sender and receiver act as receiver during frame transmissions (no concurrent space exploitation of the channel)



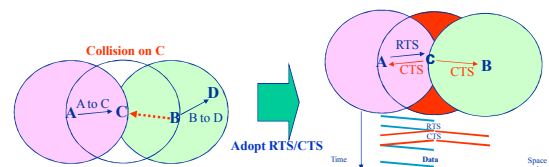
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FAMA: cs + slotted RTS/CTS + ACK

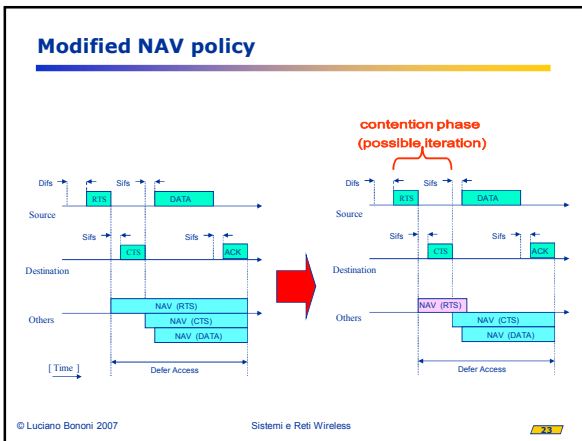
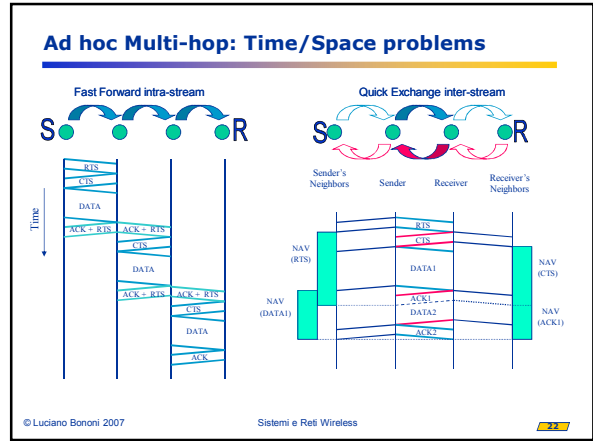
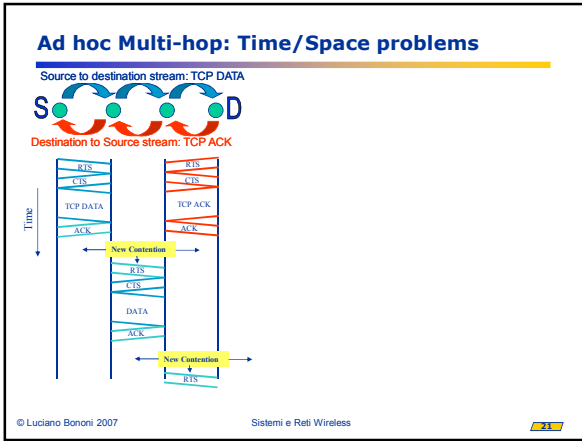
- FAMA: **re-introduces carrier sensing** before both slotted RTS/CTS
- Introduces lower bound for size of RTS/CTS and CTS-dominance
- Floor acquisition: principle for time and space contention



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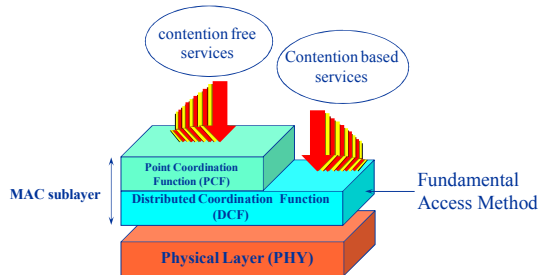
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- ### CSMA/CA: the IEEE 802.11 Wireless LAN
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 - 2 coordination functions co-exist in a superframe structure (time division)
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 - minimum bandwidth guarantee
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IEEE 802.11 MAC protocol architecture



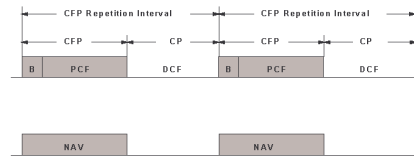
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Point coordinated mode (PCF)

- point coordinated mode is a contention free, optional service
 - can co-exist with the DCF in a superframe structure.
- central coordinator, i.e. the access point
 - manages stations belonging to its access list.
 - guaranteed to access the channel in a contention-free environment.



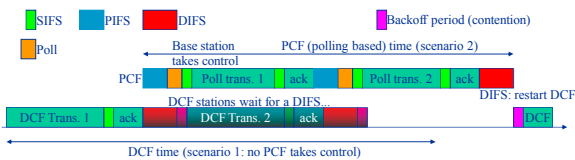
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DCF and PCF control: IFS

- Each station performs a carrier sensing activity when accessing the channel
- priority is determined by Interframe spaces (IFS):
 - Short IFS (SIFS) < Point IFS (PIFS) < Distributed IFS (DIFS)
 - after a SIFS only the polled station can transmit (or ack)
 - after a PIFS only the Base Station can transmit (and PCF takes control)
 - after a DIFS every station can transmit according to basic access CSMA/CA (DCF restarts)



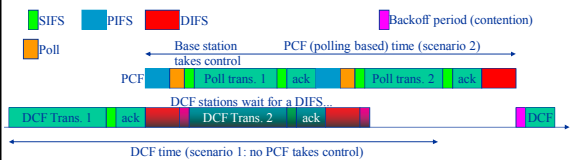
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Point Coordination Function (PCF)

- during the PCF time the base station has priority in accessing the channel
 - Base Station waits for a PIFS after a transmission and takes control (DCF stations must wait for DIFS>PIFS)
 - base station polls stations that reserved the channel
 - at the end of the PCF period the Base Station releases the channel and DCF restarts (after a DIFS)



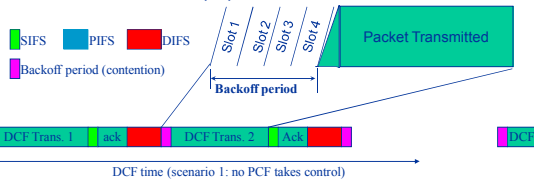
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Distributed Coordination Function (DCF)

- Basic Access mode:
 - Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) access scheme (listen before transmit)
 - carrier sensing performed to detect ongoing transmissions
 - Binary Exponential Backoff over slotted idle time
 - each station randomly selects the transmission slot in a variable sized Contention Window**
 - no Collision Detection (CD)

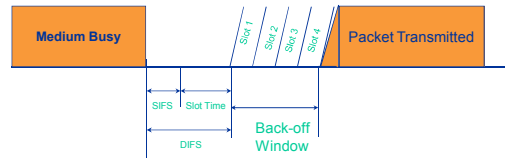


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CSMA/CA Access Mechanism



- CSMA/CA is an efficient protocol for data traffic, like Ethernet
- Listen before transmit
- Always back-off before a transmission or retransmission
 - Designed to provide fair access to the medium

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DCF Backoff procedure

• Selection of a random Backoff Time

CW_i=contention window size at the i-th transmission attempt. CW_i is doubled after each collision experienced (to reduce the contention)

$$\text{BackoffTime}(i) = (CW_i * \text{random}()) * \text{SlotTime}$$

i	1	2	3	4	5	6	7
CW _i	15	31	63	127	255	511	1023

• Reduction of the Backoff Time

After an idle DIFS period from the last transmission, a station decrements its Backoff Time by a Slot_{time} for each slot where **no activity is sensed on the medium**.

• Frozen

As soon as the medium is determined to be busy, the backoff procedure is suspended.

• Transmission

When the Backoff Time reaches zero, the station starts the transmission.

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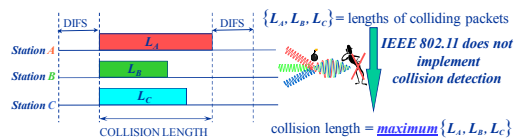


DCF basic access: overview

• Successful transmission



• Collision: no CD



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IEEE 802.11 Contention Control

- Effect of high contention = many collisions

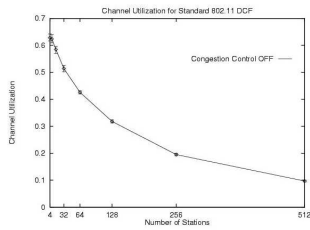


FIG. 1. Channel utilization of Standard 802.11 DCF

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IEEE 802.11 Contention Control

- Information known due to carrier sense



FIG. 2. A sample of the channel state observed by each station.

$$\text{Slot Utilization} = \text{Num Busy Slots} / \text{Initial Backoff}$$

Slot Utilization in [0..1]

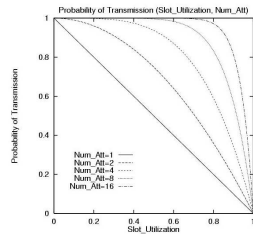
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IEEE 802.11 Contention Control

- Adoption of Slot Utilization in Distributed contention control (DCC)
- Probability of Transmission = P_T
- $P_T = (1 - S_U)^{\text{Num_Att}}$



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IEEE 802.11 Contention Control

- Probabilistic Distributed Contention Control

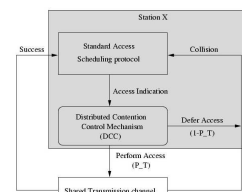
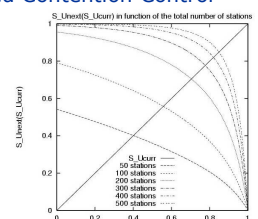


FIG. 3. Architectural collocation of DCC.

Extends 802.11 MAC



Stable (avoids collapse)

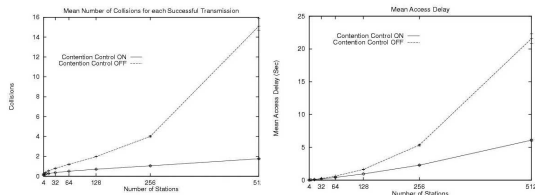
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IEEE 802.11 Contention Control

- DCC => better performance (no overheads)



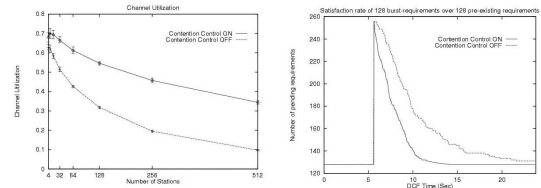
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IEEE 802.11 Contention Control

- DCC => better performance (no overheads)



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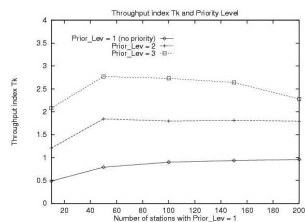
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IEEE 802.11 Contention Control

- DCC distributed priority mechanism

$$P_T = (1 - S_U)^{\text{Num_Att} \cdot \text{Prior_Lev}}$$



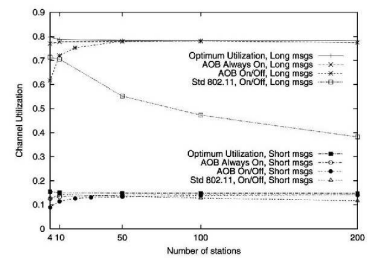
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IEEE 802.11 Contention Control

- AOB = optimum performance
- No need to estimate number of stations



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