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# Random access for dense networks: Design and Analysis of Multiband CSMA/CA

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**INSA** | INSTITUT NATIONAL  
DES SCIENCES  
APPLIQUÉES  
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Jean-Marie Gorce

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## Outline

1. Context & Overview
2. M - CSMA/CA - RTS/CTS
3. Scheduled M - CSMA/CA - RTS/CTS
4. Joint PHY-MAC analysis
5. Conclusions & Perspectives

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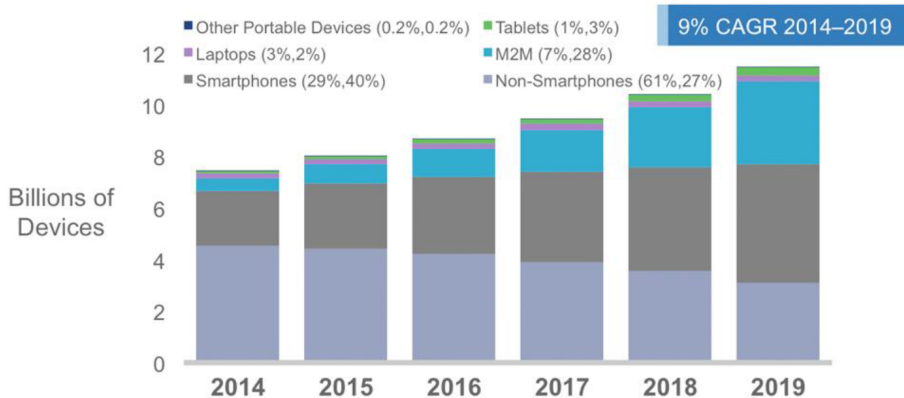


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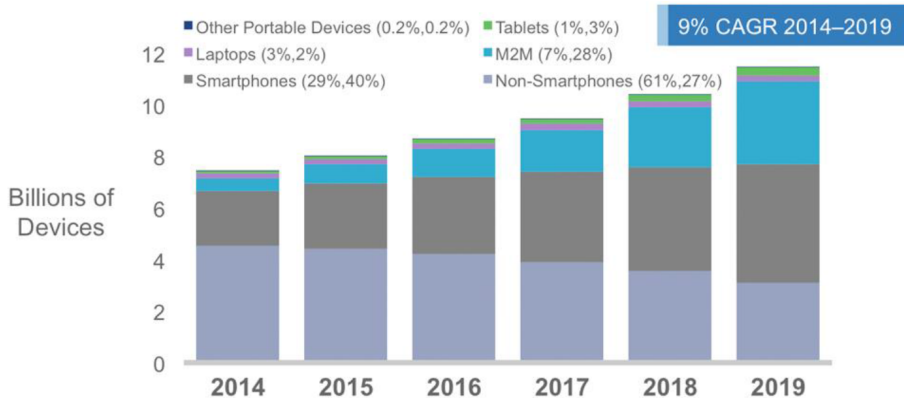
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Figures in parentheses refer to 2014, 2019 device share.

Source: Cisco VNI Mobile, 2015

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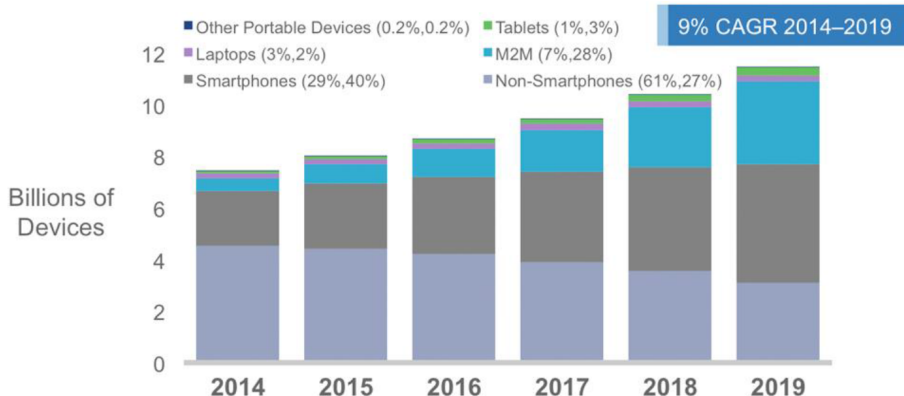


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### ► Context : M2M scenarios

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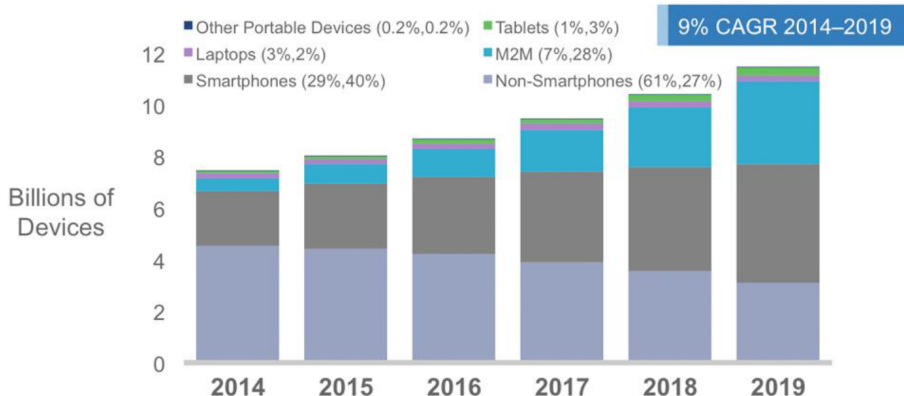


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- ▶ Context : M2M scenarios
  - ▶ Coordinated and centralized communication.

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- ▶ Context : M2M scenarios
  - ▶ Coordinated and centralized communication.
  - ▶ Huge amount of devices shall work opportunistically.

## Context & Overview

- ▶ Requirements



## Context & Overview

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## Context &amp; Overview

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- Plug & Play, straightforward, cheap and efficient deployment.

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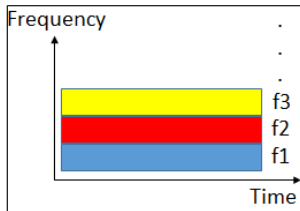


- Plug & Play, straightforward, cheap and efficient deployment.
- Distributed manner with unknown number of devices.
- Self-Organized resource management integration for scalability.

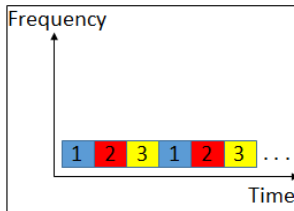
# Context & Overview

## Scheduled access techniques

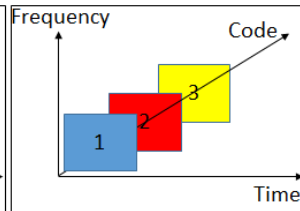
FDMA (Frequency Division Multiple Access)



TDMA (Time Division Multiple Access)



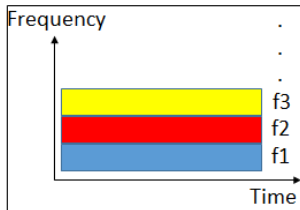
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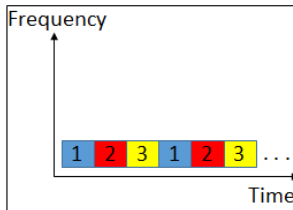
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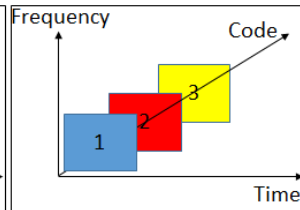
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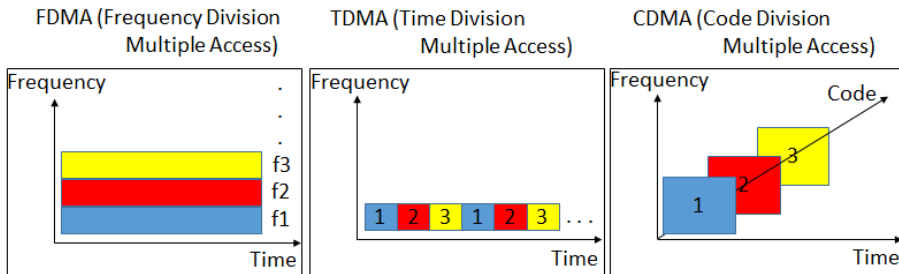
CDMA (Code Division Multiple Access)



- ▶ Central station to manage other nodes.

## Context & Overview

### Scheduled access techniques



- ▶ Central station to manage other nodes.
- ▶ Need for control channels, resources allocations,...

## Context & Overview

Random access techniques

- ▶ Aloha



## Context & Overview

### Random access techniques

- ▶ Aloha
  - ▶ Pure Aloha [Ambrasson70 [Yan86]

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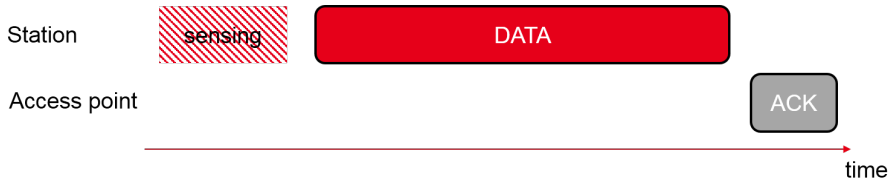
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  - ▶ CSMA/CA - RTS/CTS (Request To Send / Clear To Send)

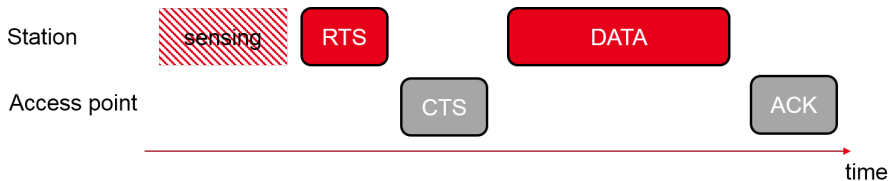
# Context & Overview

## Basic CSMA/CA Algorithm



## Context & Overview

### CSMA/CA - RTS/CTS Algorithm





## Context & Overview

Why CSMA/CA?

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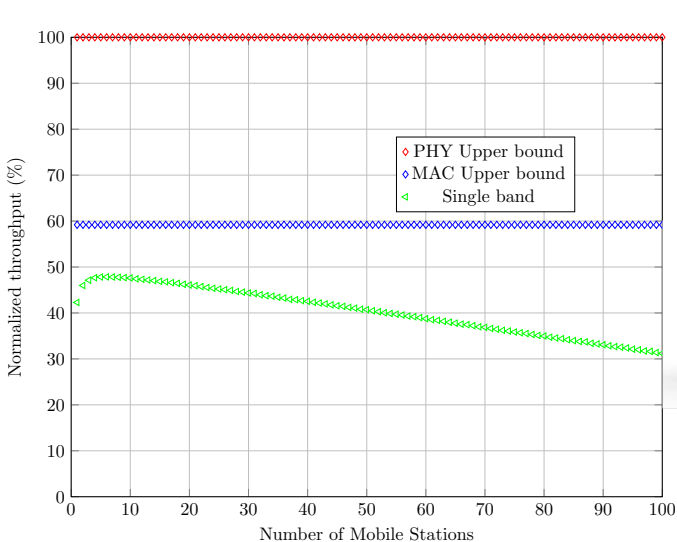
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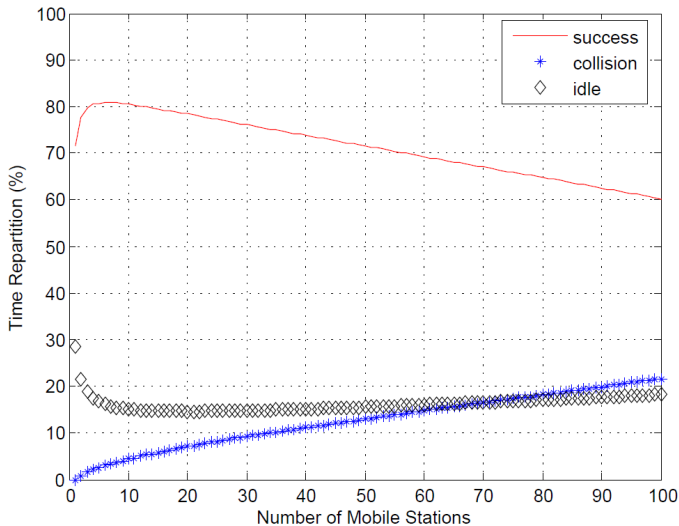
Problematic

CSMA/CA overhead



# Context & Overview

Discussion



## Context & Overview

Previous works

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    - ▶ low traffic : high rates users are penalized.

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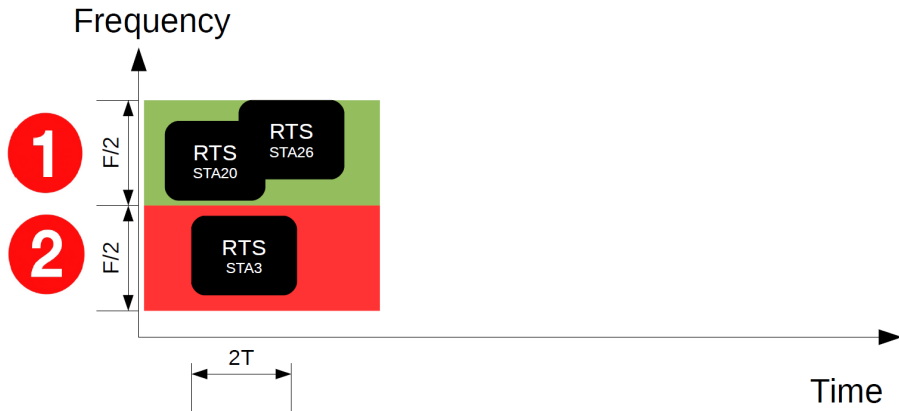


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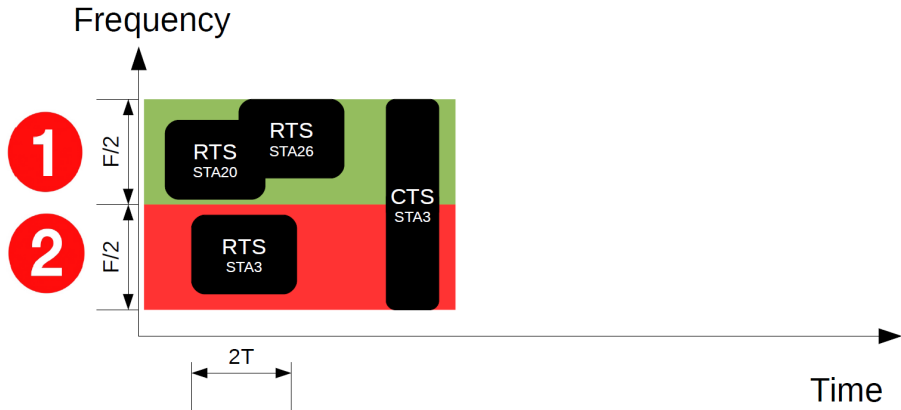
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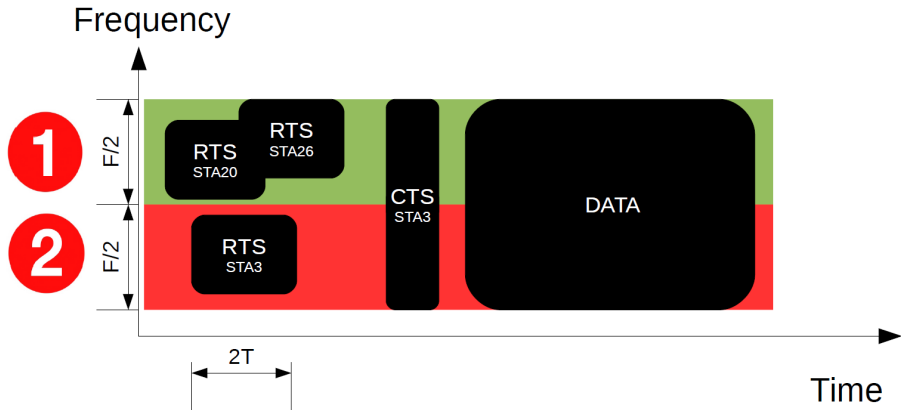




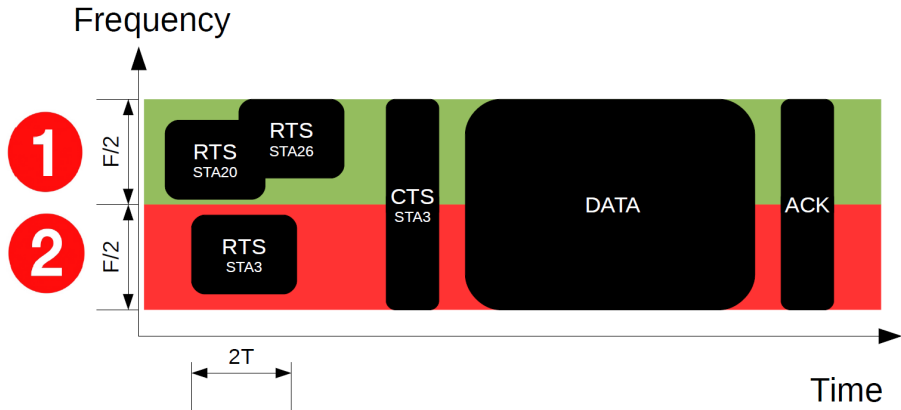
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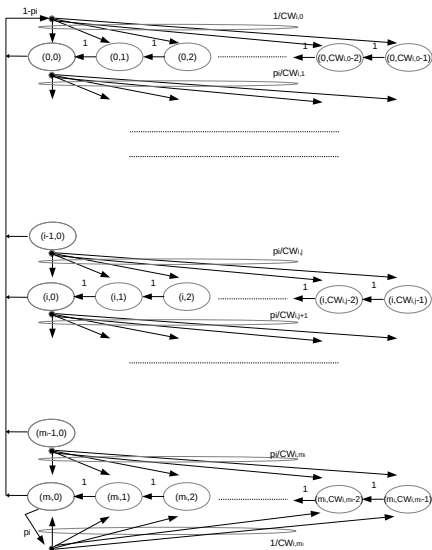
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  - ▶ All users have same bitrates and same amount of time to transmit.
  - ▶ All users are divided into sets and each set of users is assigned to a predefined sub-channel.

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Analytical approach



$$\pi_i = \frac{2}{1 + W_{min_i} + p_i W_{min_i} \sum_{k=0}^{m_i-1} (2p_i)^k}$$

# M - CSMA/CA - RTS/CTS

Analytical derivations

## Bianchi model

$$P_{tr} = 1 - (1 - \pi)^N$$

$$P_s = \frac{N\pi(1 - \pi)^{N-1}}{1 - (1 - \pi)^N}$$

$$S = \frac{E[\text{Payload information transmitted in a slot time}]}{E[\text{Duration of slot time}]}$$

$$= \frac{P_s P_{tr} L}{P_s P_{tr} T_s + P_{tr}(1 - P_s) T_c + (1 - P_{tr}) T_{id}}$$

## M - CSMA/CA - RTS/CTS model

$$P_{tr}^n = 1 - \prod_{i=1}^n (1 - \pi_i)^{N_i}$$

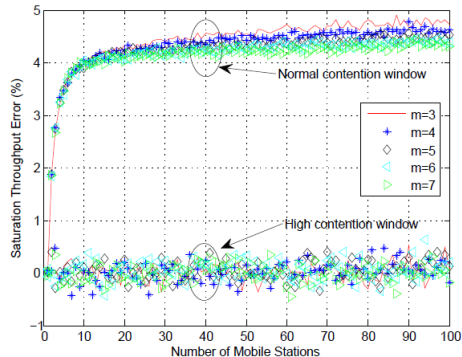
$$P_s^n = \frac{1 - \prod_{i=1}^n (1 - N_i \pi_i (1 - \pi_i)^{N_i - 1})}{1 - \prod_{i=1}^n (1 - \pi_i)^{N_i}}$$

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$$= \frac{P_s^n \times P_{tr}^n L}{P_s^n \times P_{tr}^n T_s + P_{tr}^n \times (1 - P_s^n) T_c + (1 - P_{tr}^n) T_{id}}$$

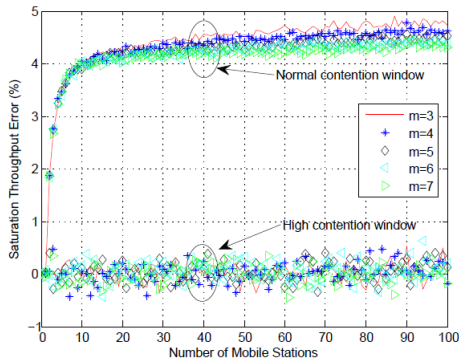
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Model validation



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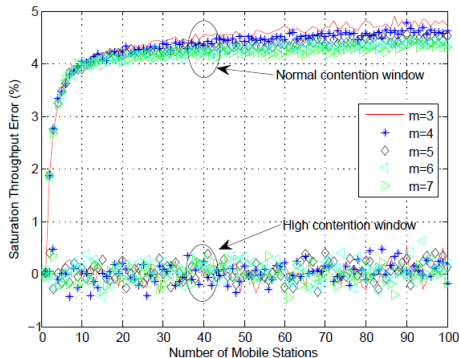
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## M - CSMA/CA - RTS/CTS

Performance evaluation

- ▶ Home-made event-driven matlab simulator models the protocol behavior.

Packet payload	8184 bits
MAC header	272 bits
PHY header	128 bits
ACK length	112 bits + PHY header
RTS length	160 bits + PHY header
CTS length	112 bits + PHY header
Channel Bit Rate	72.2 Mbit/s
Propagation Delay	1 $\mu$ s
SIFS	10 $\mu$ s
Slot Time	9 $\mu$ s
DIFS	28 $\mu$ s

TABLE: PHY layer parameters for 802.11n 20Mhz

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  - ▶ 3 RTS bands and 100 nodes, we can achieve :
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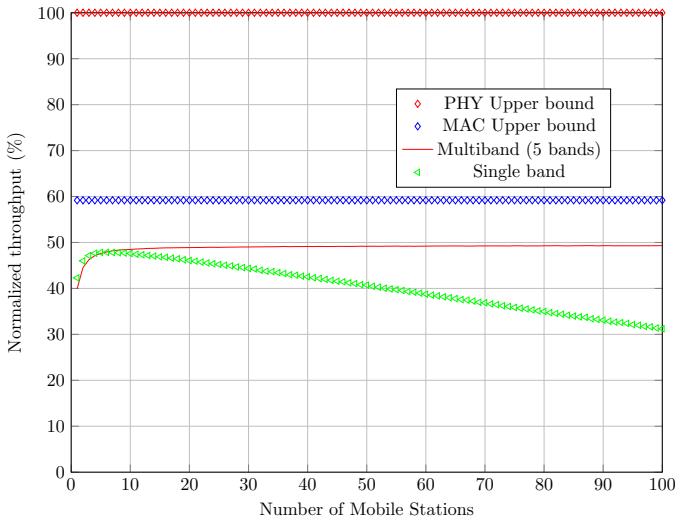
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    - ▶ Packet drop probability is divided by  $\approx 3$



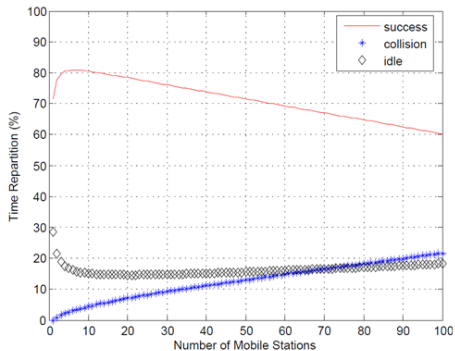
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Performance comparison

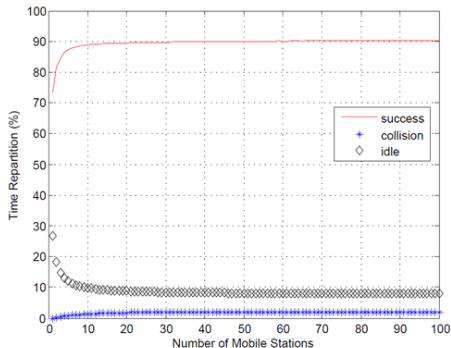


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## Discussion



Single band CSMA/CA - RTS/CTS



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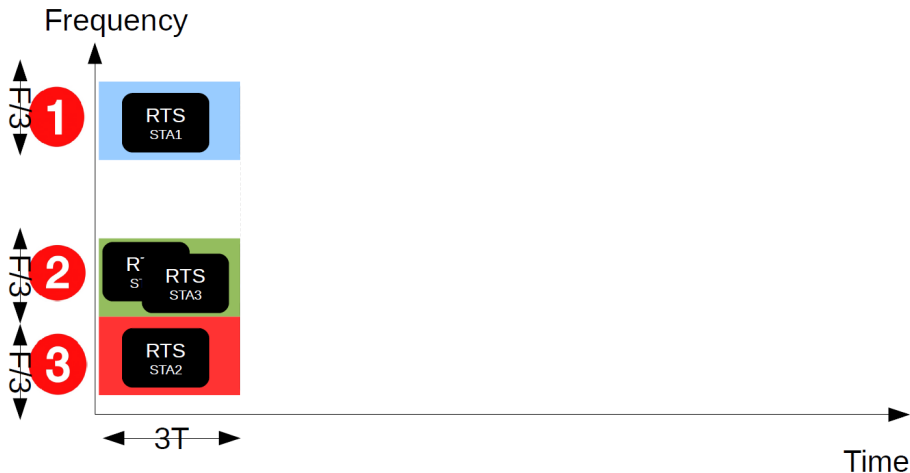
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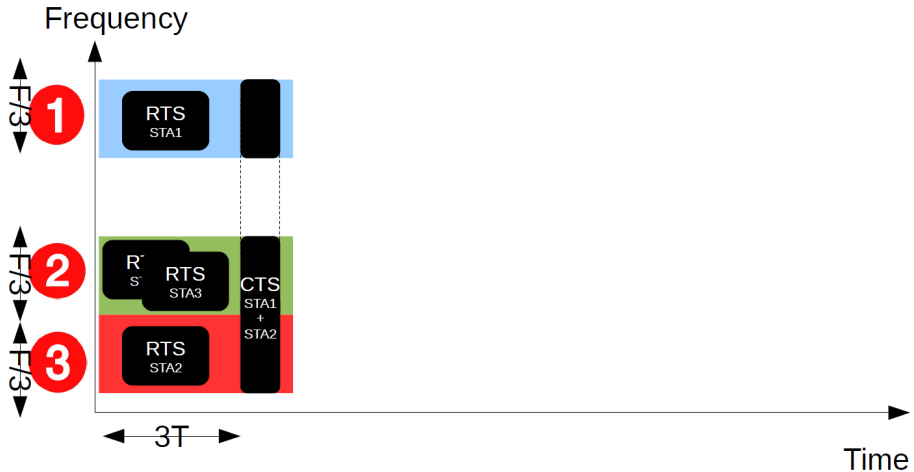
# Scheduled M - CSMA/CA - RTS/CTS

System Model



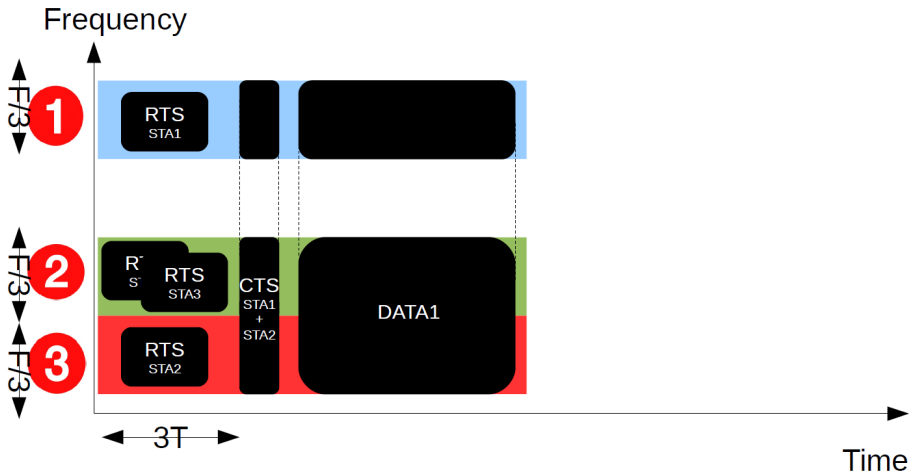
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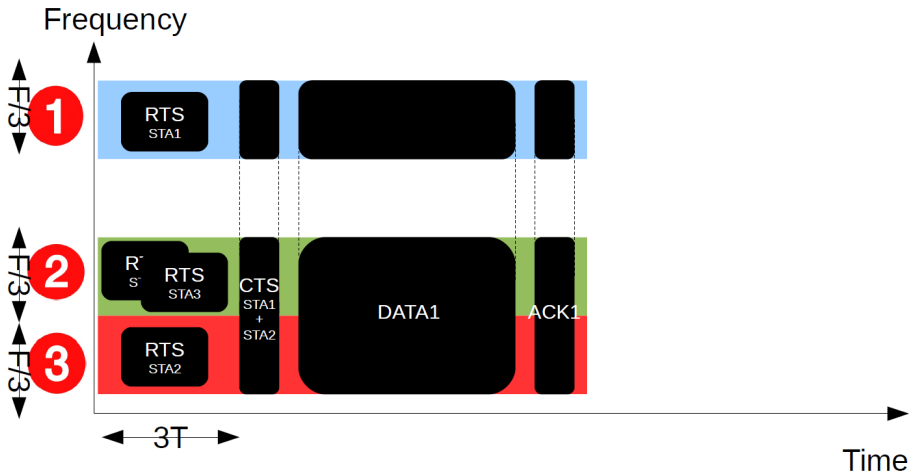
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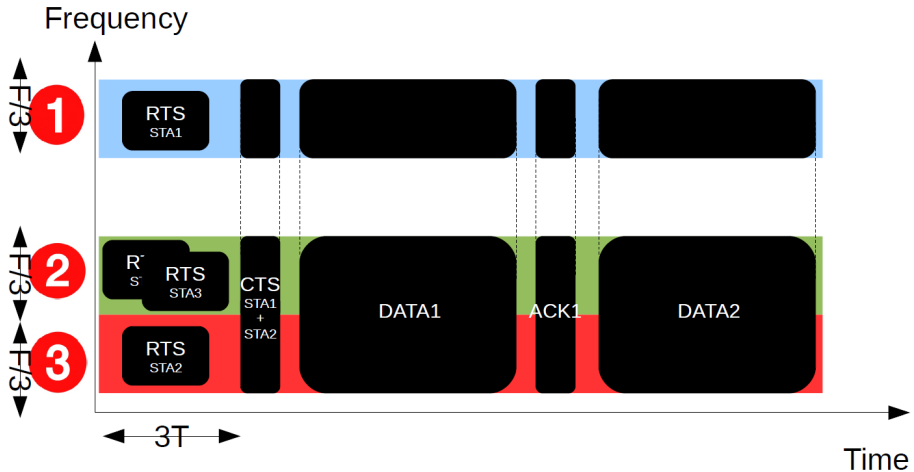
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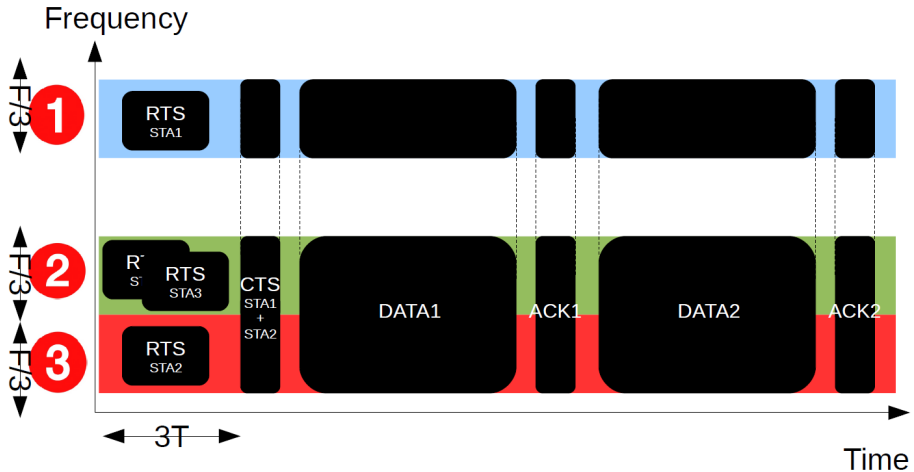
System Model





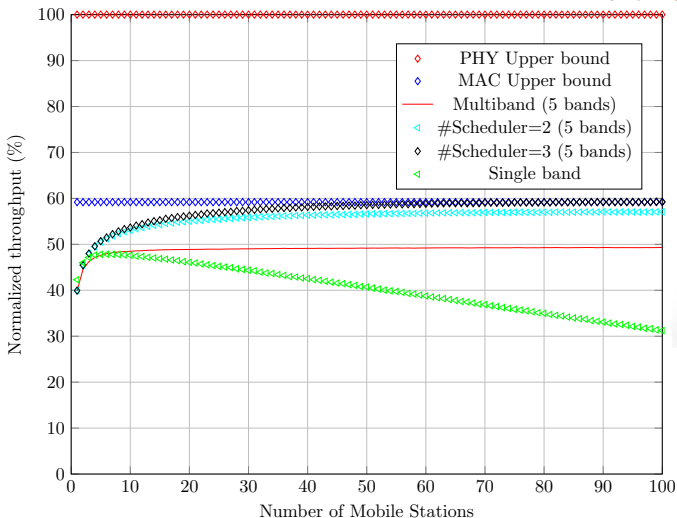
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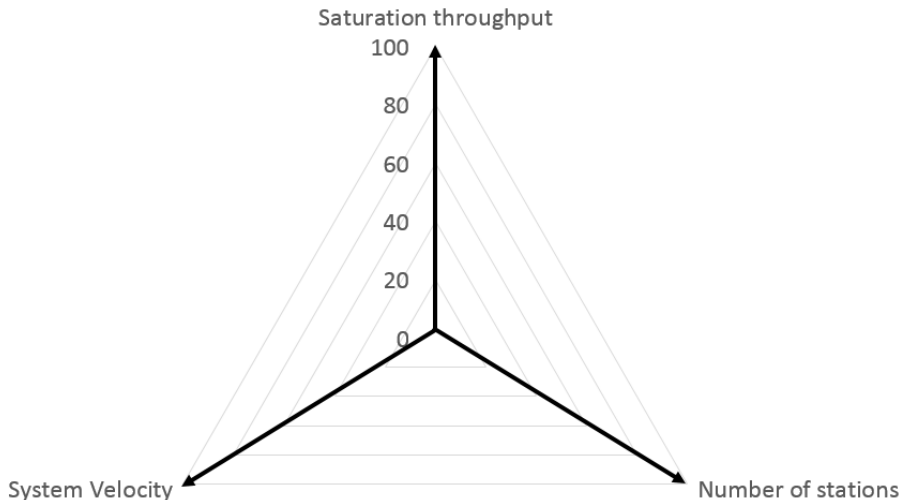
# Scheduled M - CSMA/CA - RTS/CTS

Performance comparison



# Scheduled M - CSMA/CA - RTS/CTS

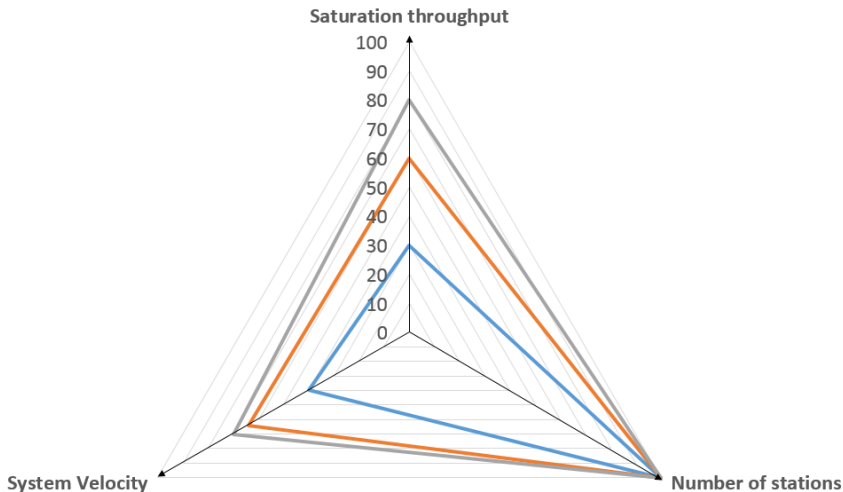
Synthesis



# Scheduled M - CSMA/CA - RTS/CTS

Synthesis for dense networks

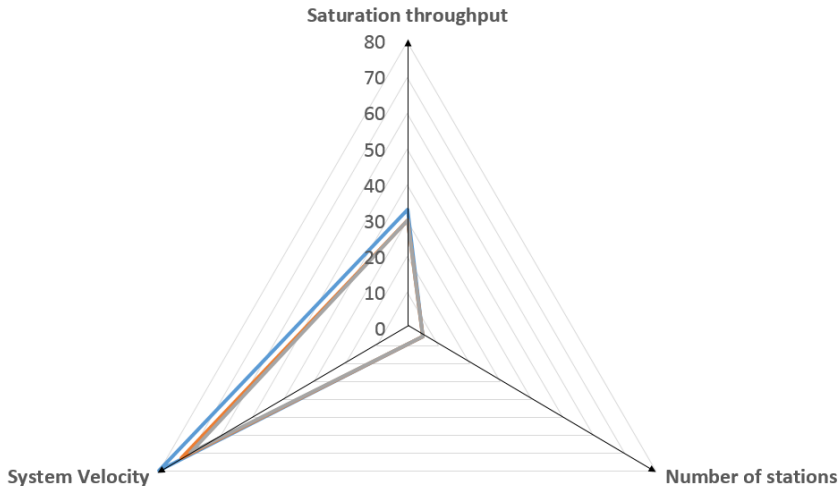
— Single band CSMA/CA-RTS/CTS    — M-CSMA/CA-RTS/CTS    — Scheduled M-CSMA/CA-RTS/CTS



# Scheduled M - CSMA/CA - RTS/CTS

Synthesis for unloaded networks

— Single band CSMA/CA-RTS/CTS    — M-CSMA/CA-RTS/CTS    — Scheduled M-CSMA/CA-RTS/CTS



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## Outline

1. Context & Overview
2. M - CSMA/CA - RTS/CTS
3. Scheduled M - CSMA/CA - RTS/CTS
4. Joint PHY-MAC analysis
5. Conclusions & Perspectives

# Joint PHY-MAC analysis

Scientific approach

- ▶ Physical layer effect on M-CSMA/CA - RTS/CTS

# Joint PHY-MAC analysis

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  - ▶ Successful transmission ratio (STR) for AWGN and D fading channels

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  - ▶ SIR analytical expressions considering capture effect



# Joint PHY-MAC analysis

Capture effect Scenario



# Joint PHY-MAC analysis

Capture effect Scenario



$$SIR(k, i) = \frac{\frac{1}{R_i^\alpha}}{\sum_{\substack{j=1 \\ j \neq i}}^{g_k} \frac{1}{R_j^\alpha}}$$

# Joint PHY-MAC analysis

## Assumptions

- ▶ Noise is dominated by interference.

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# Joint PHY-MAC analysis

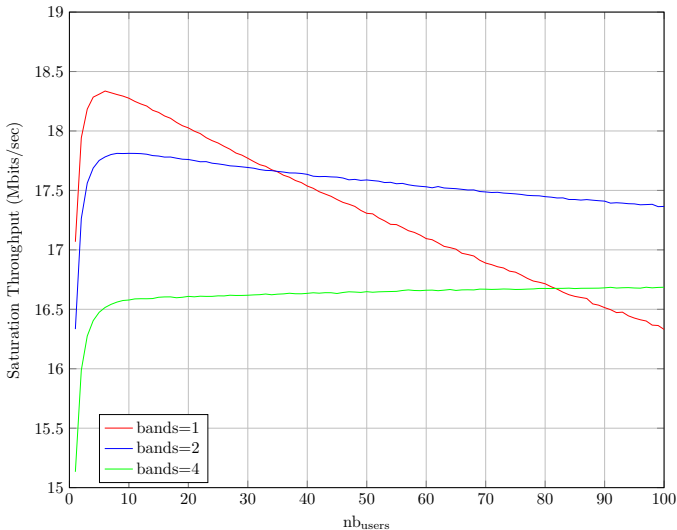
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- ▶ Only the RTS collision effect is treated.

# Joint PHY-MAC analysis

Capture effect for D fading channel with GI=8

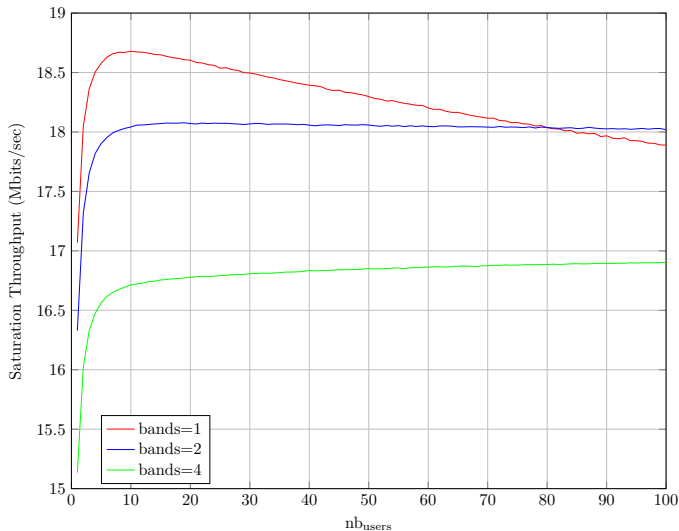
Fading 13.5 dB, R=2/3, 16QAM



# Joint PHY-MAC analysis

Capture effect for AWGN channel with GI=8

AWGN 5.5dB, R=2/3, 16QAM



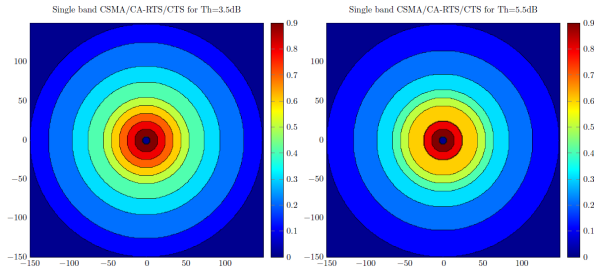
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Capture effect Scenario



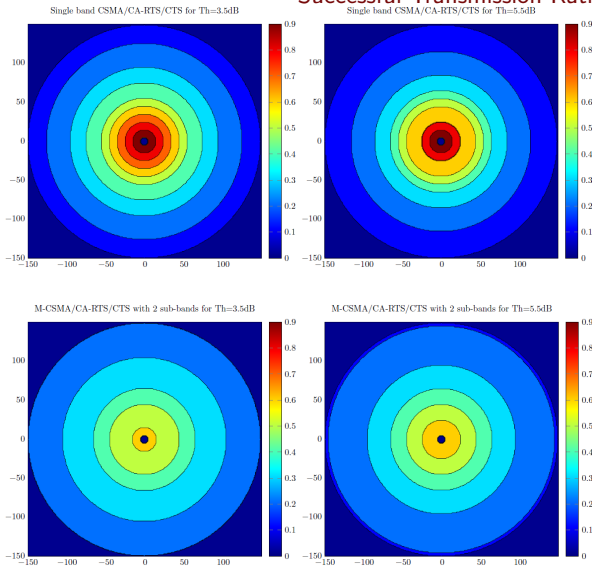
# Joint PHY-MAC analysis

## Successful Transmission Ratio for AWGN channel



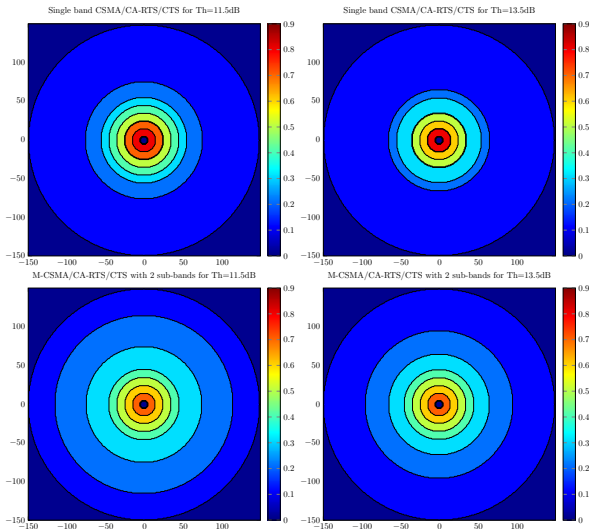
# Joint PHY-MAC analysis

## Successful Transmission Ratio for AWGN channel



# Joint PHY-MAC analysis

## Successful Transmission Ratio for D fading channel



# Joint PHY-MAC analysis

## Interband Interference

- ▶ What are the constraints if OFDM is considered ?



# Joint PHY-MAC analysis

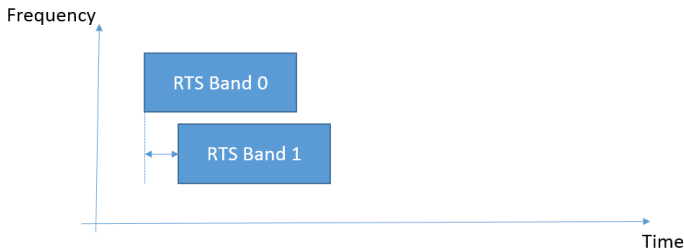
## Interband Interference

- ▶ What are the constraints if OFDM is considered?
  - ▶ OFDM is not well localized in frequency.

## Joint PHY-MAC analysis

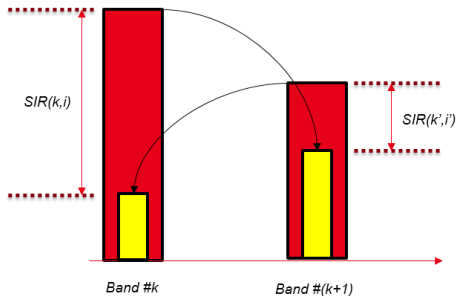
### Interband Interference

- ▶ What are the constraints if OFDM is considered ?
  - ▶ OFDM is not well localized in frequency.
  - ▶ Interband interference occurs if the received signal over all the sub-bands are not time synchronized.
    - ▶ Position in the cell.
    - ▶ Imperfect hardware implementation (response time...)



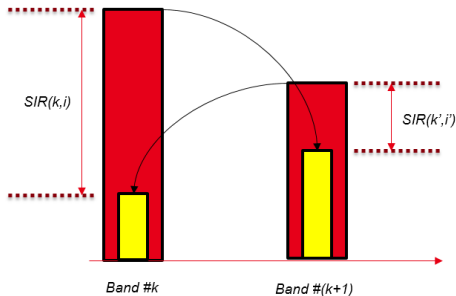
# Joint PHY-MAC analysis

## Interband Interference



# Joint PHY-MAC analysis

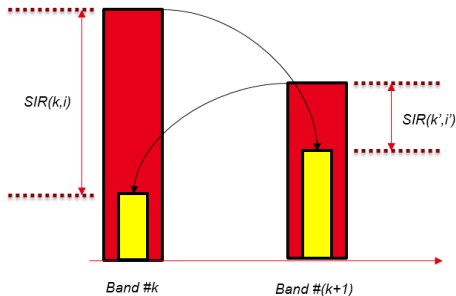
## Interband Interference



- Interband interference due to asynchronous transmissions.

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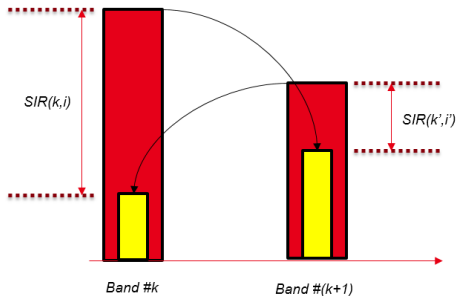
## Interband Interference



- ▶ Interband interference due to asynchronous transmissions.
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# Joint PHY-MAC analysis

## Interband Interference



- ▶ Interband interference due to asynchronous transmissions.
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# Joint PHY-MAC analysis

## Interband interference analysis

$$SIR(k, i) = \frac{\overbrace{P_R(k, i)}^{\text{useful signal}}}{\underbrace{\sum_{\substack{j=1 \\ j \neq i}}^{g_k} P_R(k, j)}_{\text{capture effect}} + \underbrace{\sum_{\substack{p=1 \\ p \neq k}}^n \sum_{j \in E_p} I(p, j, d_k(j, i))}_{\text{interband interference}}}$$

# Joint PHY-MAC analysis

## Interband interference analysis

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- If the time misalignment is lower than the guard interval duration, the orthogonality between sub-bands is guaranteed.

## Joint PHY-MAC analysis

Additional Studies

- ▶ Engineering work for IEEE 1900.7 (Radio Interface for White Space Dynamic Spectrum Access)<sup>1</sup>

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1. STANISLAV ANATOLIEVICH FILIN, DOMINIQUE NOGUET, JEAN-BAPTISTE DORÉ, **Baher Mawlawi**, OLIVIER HOLLAND, MUHAMMAD ZEESHAN SHAKIR, HIROSHI HARADA AND FUMIHIDE KOJIMA 2015.

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- ▶ System evaluation of Multiband CSMA/CA with Multi RTS<sup>3</sup>.

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# Conclusions & Perspectives

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  - ▶ The proposed strategy may be easily implemented by allocating many sub-carriers for different RTS messages.

# Conclusions & Perspectives

PhD contributions

- ▶ CSMA/CA drawbacks analysis for dense network scenarios.

# Conclusions & Perspectives

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# Conclusions & Perspectives

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- ▶ Consider the FBMC modulation.
- ▶ Energy consumption study.



## Scientific Contributions

- ▶ 3 Patents.
- ▶ 9 Conference papers.
- ▶ 2 Journals under preparation.
- ▶ 8 Technical contributions.
- ▶ Grant from COST Action IC 0902.

## Scientific Contributions

List of patents

1. **Baher Mawlawi** and Jean-Baptiste Doré “Multiple access method and system with frequency multiplexing of requests for authorisation to send data” , US 14/318,838.
2. **Baher Mawlawi**, Jean-Baptiste Doré and Jean-Marie Gorce “Multiple access method and system with frequency multiplexing of several request to send messages per source node” , US 14/533480.
3. **Baher Mawlawi** and Jean-Baptiste Doré “Submitted”.

## Scientific Contributions

List of journal papers

1. **Baher Mawlawi**, Jean-Baptiste Doré and Jean-Marie Gorce, “A Multiband CSMA/CA Strategy for Crowded Single Band Multicarriers Wireless LAN”, under preparation.
2. **Baher Mawlawi** and Jean-Baptiste Doré, “A PHY-MAC Cross Layer Study for WRAN based on FBMC Waveforms”, under preparation.

# Scientific Contributions I

List of conference papers

1. **Baher Mawlawi**, Jean-Baptiste Doré, “CSMA/CA Bottleneck Remediation In Saturation Mode With New Backoff Strategy”, 6th International Workshop on Multiple Access Communications, 16-17 December 2013, Vilnius, Lithuania.
2. **Baher Mawlawi**, Jean-Baptiste Doré, Nikolai Lebedev and Jean-Marie Gorce, “Analysis of Frequency Channel Division Strategy for CSMA/CA with RTS/CTS Mechanism”, Eighth International Conference on Sensing Technology (ICST), 2-5 September 2014, Liverpool, Uk.
3. **Baher Mawlawi**, Jean-Baptiste Doré, Nikolai Lebedev and Jean-Marie Gorce, “Performance Evaluation Of Multiband CSMA/CA With RTS/CTS For M2M Communication With Finite Retransmission Strategy”, International Conference on Selected Topics in Mobile and Wireless Networking (MoWNet), 8-9 September 2014, Rome, Italy.

## Scientific Contributions II

List of conference papers

4. **Baher Mawlawi**, Jean-Baptiste Doré, Nikolai Lebedev and Jean-Marie Gorce, “Multiband CSMA/CA with RTS-CTS Strategy”, IEEE 10th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), 8-10 October 2014, Larnaca, Cyprus.
5. **Baher Mawlawi**, Jean-Baptiste Doré, Nikolai Lebedev, Jean-Marie Gorce “CSMA/CA with RTS/CTS Overhead Reduction for M2M communication”, IEEE WCNC 2015 - Workshop - NGWIFI, 9-12 March 2015, New Orleans, LA USA.
6. **Baher Mawlawi**, Jean-Baptiste Doré, and Vincent Berg “Optimizing Contention Based Access Methods for FBMC Waveforms”, International Conference on Military Communications and Information Systems ICMCIS (former MCC), May 2015, Cracow, Poland.

## Scientific Contributions III

List of conference papers

7. **Baher Mawlawi** and Jean-Baptiste Doré “CSMA/CA with RTS/CTS Overhead Reduction for M2M Communication with Finite Retransmission Strategy”, IEEE International Wireless Communications & Mobile Computing Conference, August 2015, Dubrovnik, Croatia.
8. **Baher Mawlawi**, Jean-Baptiste Doré, Nikolai Lebedev, Jean-Marie Gorce “Modélisation Analytique du protocole Multi-Bande CSMA/CA”, 25ème colloque Grets, 8-11 Septembre 2015, Lyon, France.
9. Stanislav Anatolievich Filin, Dominique Noguet, Jean-Baptiste Doré, **Baher Mawlawi**, Olivier Holland, Muhammad Zeeshan Shakir, Hiroshi Harada and Fumihide Kojima “IEEE 1900.7 Standard for White Space Dynamic Spectrum Access Radio Systems”, IEEE International Conference on Standards for Communications and Networking, 28-30 October 2015, Tokyo, Japan.

# Scientific Contributions I

## Grants

- ▶ COST Action IC 0902, Best tutorial days participant, 11-13 February 2013, Castelldefels-Barcelona, Spain.

# Scientific Contributions I

Technical contributions

1. Jean-Baptiste Doré, **Baher Mawlawi**, Dominique Noguét, “MAC Draft Standard”, IEEE 1900.7 White Space Radio, 26-29 August 2014, Piscataway, NJ, USA.
2. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “MAC Functional Description”, IEEE 1900.7 White Space Radio, 08-10 April 2014, Grenoble, France.
3. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “MAC Architecture”, IEEE 1900.7 White Space Radio, 08-10 April 2014, Grenoble, France.
4. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “Novel backoff strategy for bottleneck remediation”, IEEE 1900.7 White Space Radio, 02-05 December 2013, Tokyo, Japan.



## Scientific Contributions II

Technical contributions

5. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “Dynamic Spectrum Access Techniques”, IEEE 1900.7 White Space Radio, 26-29 August 2013, Arlington, USA.
6. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “CSMA/CA Analysis”, IEEE 1900.7 White Space Radio, 26 June 2013, Grenoble, France.
7. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “Analysis of Scenarios from an Access Scheme Perspective”, IEEE 1900.7 White Space Radio, 13 March 2013, Grenoble, France.
8. **Baher Mawlawi**, Jean-Baptiste Doré, Dominique Noguét, “White Space Dynamic Spectrum Access Radio Systems”, IEEE 1900.7 White Space Radio, 20 February 2013, Grenoble, France.

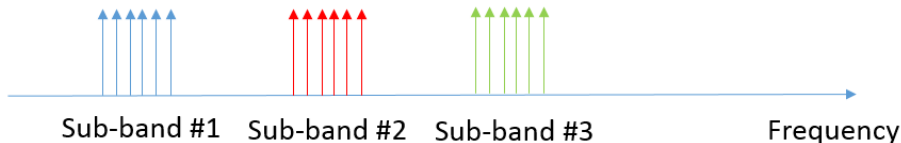
Thanks for your attention !





## Backup slides

- ▶ How to implement the M-CSMA/CA ?
  - ▶ Multicarrier waveforms (OFDM) are by construction good candidates.
    - ▶ Carriers allocations



## Backup slides

Low bitrate with coexistence



High bitrate without coexistence

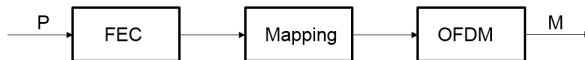


## Backup slides

MCS index	Coding rate	Modulation
0	1/2	QPSK
1	2/3	QPSK
2	3/4	QPSK
3	1/2	16QAM
4	2/3	16QAM
5	3/4	16QAM
6	1/2	64QAM
7	2/3	64QAM
8	3/4	64QAM

TABLE: List of MCS Index Values.

## Backup slides



$$T = L - STF + L - LTF + L - SIG + Data \quad (1)$$

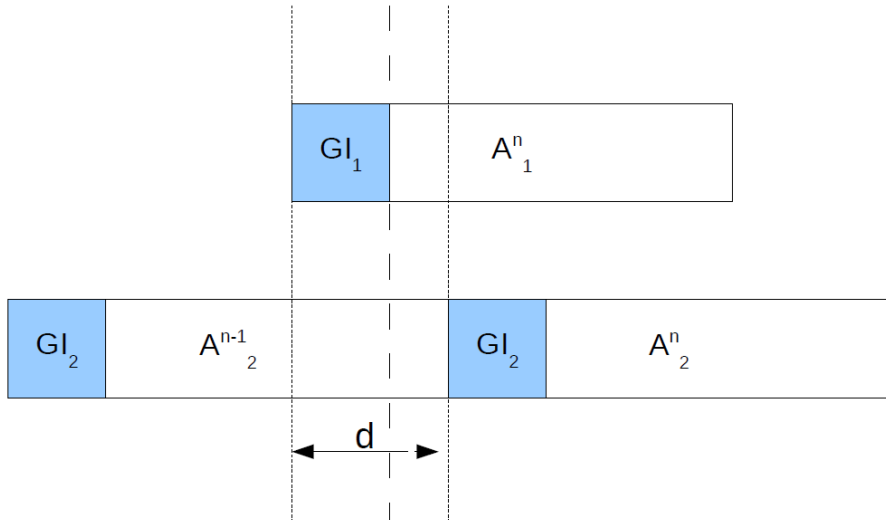
$$T = 20\mu s + M(N_c + GI)/B$$

$$M = \left\lceil \frac{\left\lceil \frac{P}{R} \right\rceil}{N_a} \right\rceil \quad (2)$$

where  $R$  is the coding rate,  $m$  is the modulation order and  $N_a$  is the number of active sub-carriers used to send the packet of length  $P$  bits.



# Backup slides



# Backup slides

