

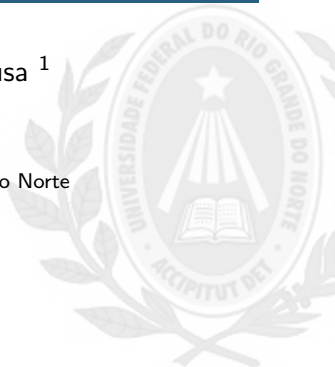
Millimeter-Wave: A Very Brief Introduction

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Sumário

- 1 Introdução
- 2 mmWave
- 3 Módulo NS3
- 4 Referencias



Introdução

Motivações

How to Increase Rate in Cellular?

Shannon Formula

$$C = W \log_2(1 + SINR)$$

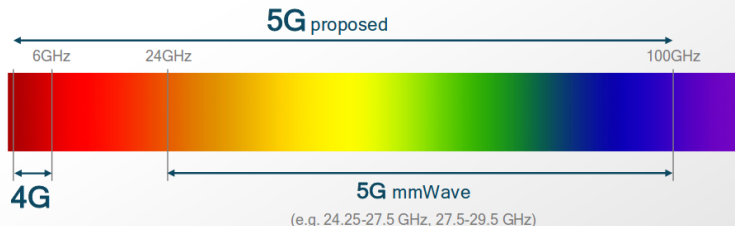
Rate per user Bandwidth per user, antenna degrees of freedom Spectral efficiency

Current coding methods close to spectral efficiency bound

Most techniques for 5G: Increase degrees of freedom

- Number of cells → Densification, greater bandwidth per user in each cell
- Bandwidth → Millimeter wave
- Number of antennas → Massive MIMO, higher spatial degrees of freedom

Características Principais das comunicações mmWave



- 1 30GHz a 300GHz (10mm a 1mm)
- 2 Faltam estudos e medições acima de 100GHz
- 3 Largas faixas disponíveis
- 4 Características de propagação muito restritas
- 5 Massive Mimo (Small antenna array)
- 6 Beamforming digital ainda impraticável

Millimeter-Wave Propagation Characteristics

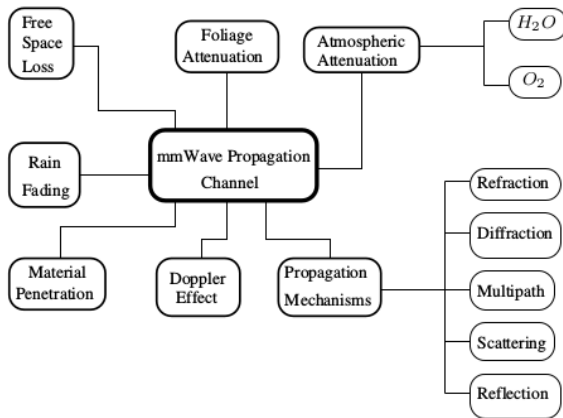


Figure 4. mmWave propagation characteristics.



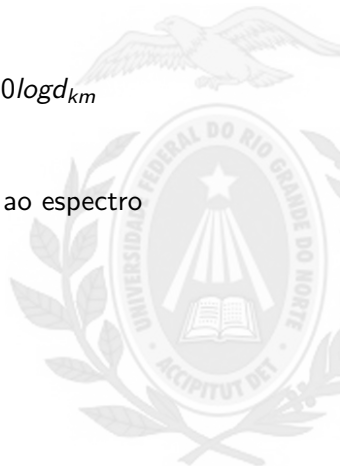
Millimeter-Wave Propagation Characteristics

A. Free-Space Loss

$$FSL_{[dB]} = 92.4 + 20\log f_{GHz} + 20\log d_{km}$$

Consequences:

- 1 Perdas maiores do que 30dB em relação ao espectro convencional
- 2 Células menores
- 3 Maior segurança
- 4 Menor interferência



Millimeter-Wave Propagation Characteristics

B. Atenuação Atmosférica

- 1 Faixa do 802.11ay
- 2 60GHz principal faixa de absorção Oxigênio
- 3 Maior atenuação = menor alcance = menor interferência = maior segurança
- 4 Polêmica com o órgão regulamentador americano FCC

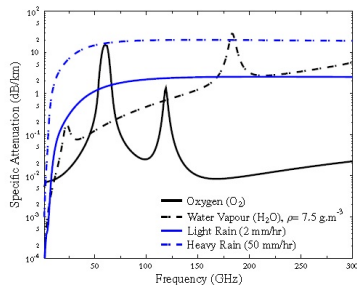


Figure 8. Specific attenuation curves of O_2 , H_2O and rain at sea level. The term ρ refers to the density of H_2O in grams per meter³ [75], [130].

Millimeter-Wave Propagation Characteristics

C. Desvanecimento Induzido por chuva

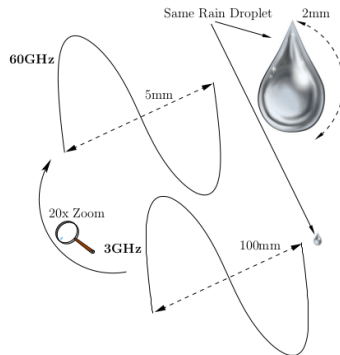


Figure 9. An illustration of a 60 GHz and a 3 GHz signal's wavelengths compared to a 2mm-sized rain droplet. Note here that the teardrop representation of the raindrop is used for illustrative reasons only and does not represent the raindrop's actual spheroidal form.



Millimeter-Wave Propagation Characteristics

D. Foliage Attenuation

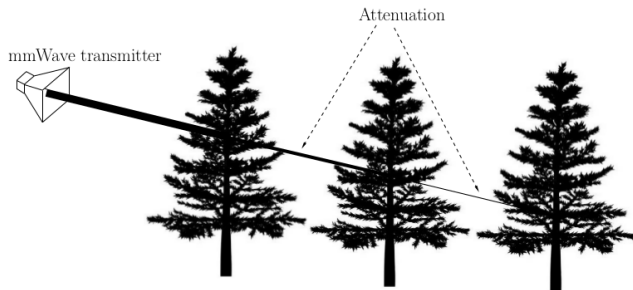


Figure 10. An illustration of foliage attenuation imposed by the presence of multiple trees, where the thickness of the lines shown illustrates the signal power.

Millimeter-Wave Propagation Characteristics

E. Material Penetration

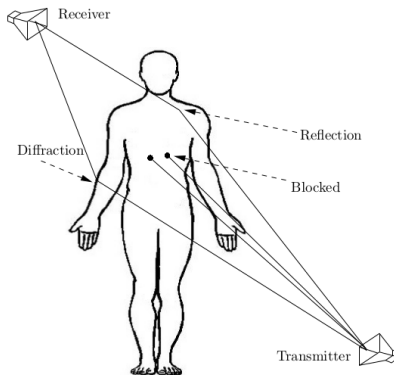


Figure 14. Human blockage of the communication between a transmitter and a receiver.



Millimeter-Wave Propagation Characteristics

F. Propagation Mechanisms

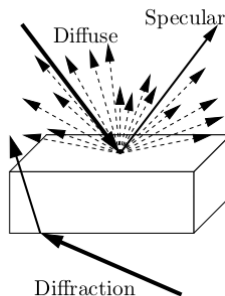


Figure 13. An illustration of different propagation mechanisms, namely specular reflection, diffuse scattering and diffraction. The rectangular reflecting/diffracting surface used is for visualization purposes only and does not intend to characterize a real scenario.



The Millimeter Wave Channel Model

- A. mmWave Channel Modeling Efforts (28GHz, 30GHz, 38GHz, 45GHz, 60GHz, 70GHz, 72GHz, 100GHz)
- B. Modeling Challenges (3D model, Measurements, Bandwidth, Mobility, Beamtracking)
- C. Path Loss and Shadowing
- D. Narrow Band Channel Model
- E. The Wideband Channel Model
- F. Spatio-Temporal Characteristics



The Millimeter Wave Channel Model

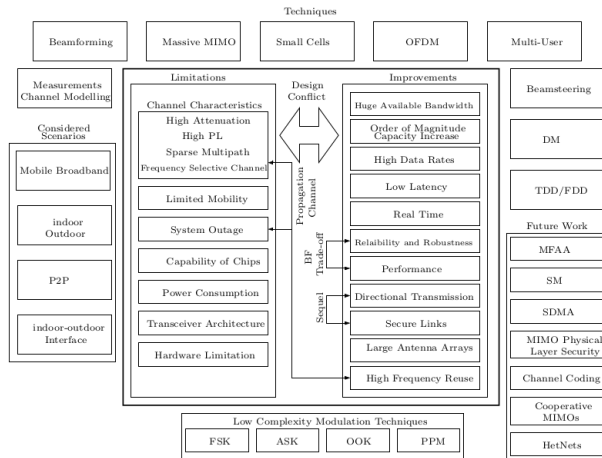


Figure 26. mmWave Technology available techniques, pros and cons, scenarios and future work.



Design Guidelines

- A. Channel Model Considerations
- B. System Design Considerations
- C. Antenna Design Considerations
- D. Link Budget Analysis

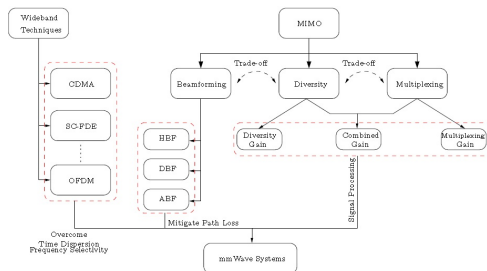
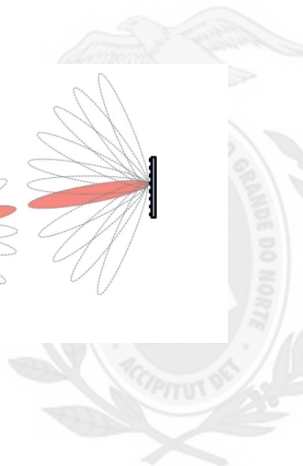
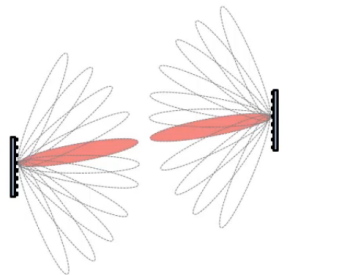
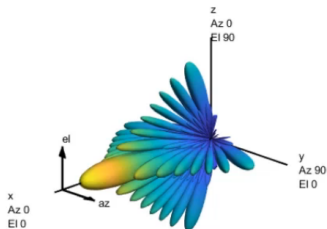


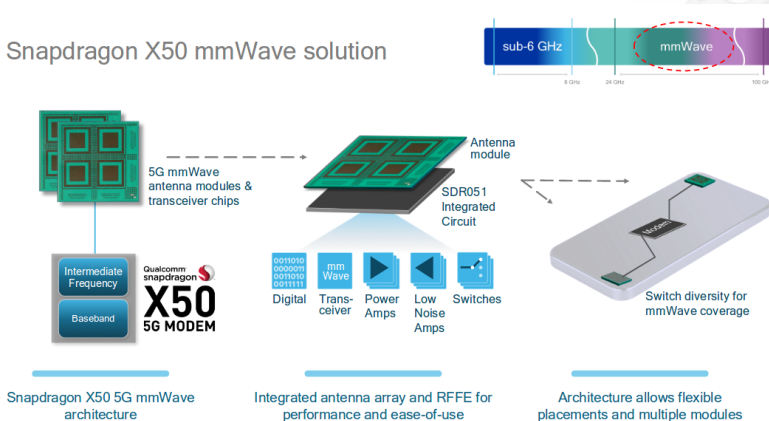
Figure 27. Design considerations for mmWave systems, which characterize the "Signal Processing" entrance to the "mmWave Technology" roundabout of Figure 2.

MIMO and Beamforming



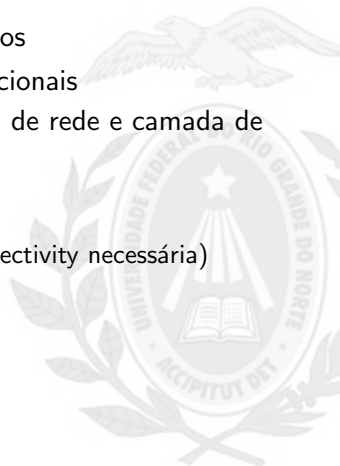
MIMO and Beamforming

Snapdragon X50 mmWave solution



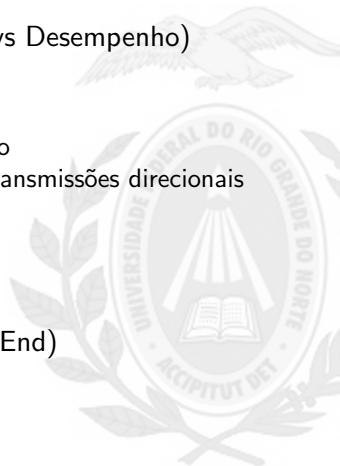
mmWave - Desafios a serem superados

- 1 Beamforming e Beam tracking adaptativos
- 2 Canais de sincronização e broadcast direcionais
- 3 Problemas com a camada MAC, camada de rede e camada de transporte
 - 1 Sombreamento
 - 2 Desvanecimento rápido
 - 3 Mudanças de link frequentes (Dual connectivity necessária)



Desafios em simulações System-Level de redes mmWave

- 1** Complexidade computacional (Precisão vs Desempenho)
- 2** Modelo do Canal
 - 1** LOS e NLOS
 - 2** Perdas de propagação e desvanecimento
 - 3** Beamforming deve ser simulado para transmissões direcionais
 - 4** Efeito doppler relevante
- 3** Considerar a Mobilidade
- 4** Células pequenas e Handover frequente
- 5** Diversos protocolos interagindo (End-to-End)



Módulo mmWave NS3

- 1 Módulo NS-3 Criado pela NYU
- 2 End-to-End Framework (MEZZAVILLA et al., 2018)
 - 1 Modelos de canais detalhados (3GPP , Ray-Tracing e Medições)
 - 2 Camada MAC adaptável (inclusive com possibilidade de HARQ adaptativo)
 - 3 RLC, PDCP, RRC realistas
 - 4 Core network configurável
 - 5 Handover entre 5G e 5G/4G
- 3 <https://github.com/nyuwireless-unipd/ns3-mmwave>

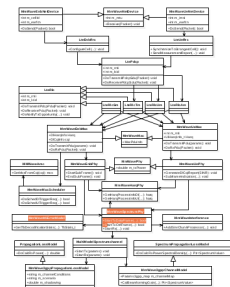


Figure 1: **ns3-mmwave** software architecture diagram for the software module.

Módulo mmWave NS3 - Classes

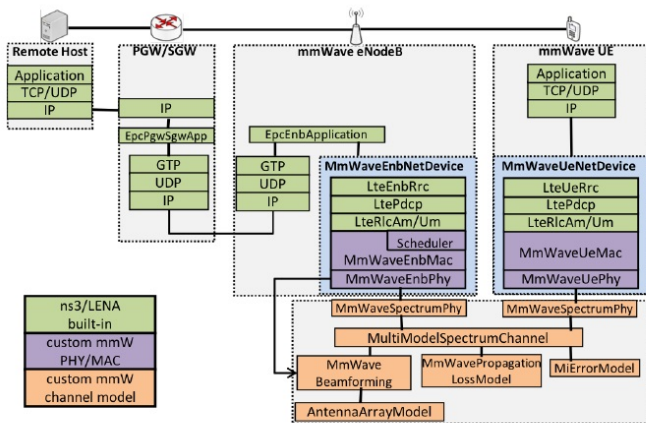
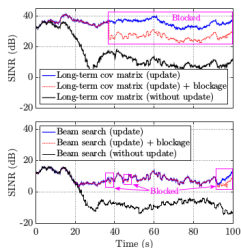


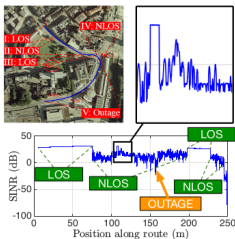
Figure 1: Class diagram of the end-to-end mmWave module.

Módulo mmWave NS3 - Modelos de Canais

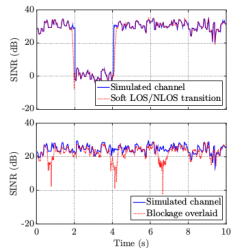
- 1.Channel and Mimo Modeling (3GPP, Ray-Tracing, NYU model)
- 2.Beamforming
- 3.Interferência
- 4.Error Model



(a) **3GPP** statistical channel model



(b) Ray-tracing Trace Model



(c) NYU Statistical Model

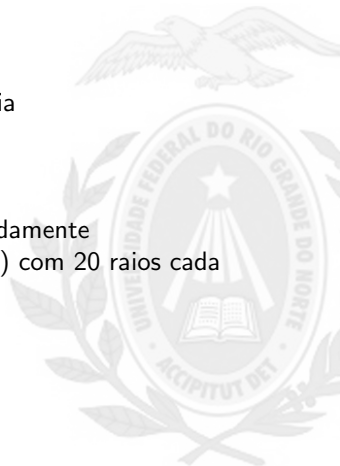
Figure 4: Example of average **SINR** plots for the three channel models.

Módulo mmWave NS3 - Modelos de Canais

1 3GPP Statistical Channel Model:

- 1 6-100GHz
- 2 Largura de banda ate 10% da frequência
- 3 Vários cenários (Rural, urbano, indoor)
- 4 Consistência espacial
- 5 Bloqueio aleatório
- 6 Matriz de canal $H(t,f)$ calculada repetidamente
- 7 Calcula até 20 multipercursos (Clusters) com 20 raios cada

2 Exige muito esforço computacional



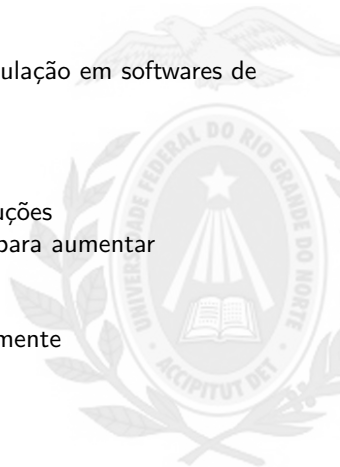
Módulo mmWave NS3 - Modelos de Canais

1 Ray-Tracing:

- 1 Modelo criado a partir de dados de simulação em softwares de Ray tracing adicionados ao NS-3

2 NYU Statistical Model

- 1 Utiliza modelos NLOS e LOS
- 2 Simula Obstrução por objetos e construções
- 3 Carrega várias matrizes pré-calculadas para aumentar desempenho
- 4 Método semi empírico
- 5 Algumas opções não verificadas formalmente



Camadas

1 Física

- 1 Frame Structure
- 2 Phy Transmission and reception

2 MAC

- 1 Adaptative Modulation and Coding
- 2 Hybrid Arq Retransmission

3 Radio Link Control

- 1 RLC AM Retransmission Modificada
- 2 Active Queue Management

4 Dual Connectivity Extension



Camada Física - Frame Structure

Estrutura de quadro baseada em Time Division Duplex (TDD).
Duração e Número de Símbolos OFDM Configuráveis pela classe
MmwavePhyMacCommom.

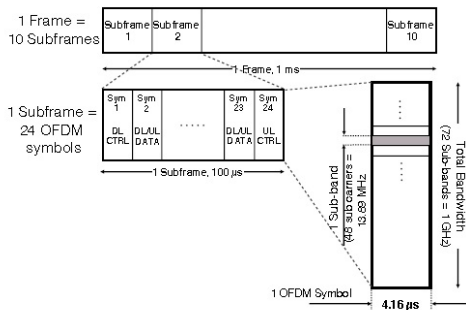


Figure 6: Proposed mmWave frame structure.



Camada Física - Transmissão e recepção

- 1 As classes MmWaveEnbPhy e MmWaveUePhy modelam a camada física das eNBs e UEs.
- 2 MmWaveEnbNetDevice e MmWaveUeNetDevice Implementam as placa de rede
- 3 Os métodos StartSubFrame() e EndSubframe() são chamados em intervalos fixos determinados pelo usuário.
- 4 Os métodos StartSlot() e EndSlot() controlam os TTI variáveis e são configuras pela camada MAC.
- 5 Para o inicio da transmissão de um Slot de dados eNB Phy chama AntennaArrayModel::ChangeBeamforming-Vector()

Camada MAC

- 1 Principal esquema de acesso considerado é TDMA. (SDMA e FDMA precisa de digital beamforming que não é prático)
- 2 Adaptive Modulation and Coding implementado e Hybrid Arq Retransmission (HARQ).

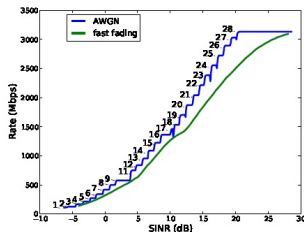


Figure 7: Rate and MCS vs. SINR for a single user under AGWN and fast-fading mmWave channels. ©[2016] ACM. Reprinted, with permission, from [28].

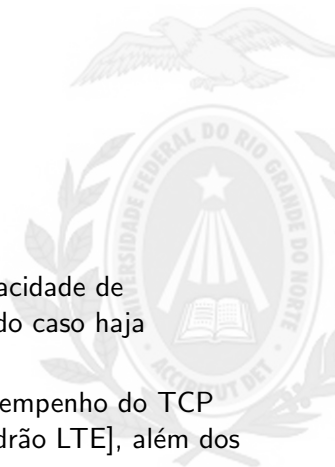
Camada MAC - Algoritmos de escalonamento

Escalonamento MAC

- 1 Round-Robin(RR)
- 2 Proportional-Fair (PF)
- 3 Earliest-Deadline-First (EDF)
- 4 Maximum Rate (MR):

Camada RLC (Radio Link Control)

- 1 Modified RLC AM Retransmission: (Capacidade de segmentação do pacote a ser retransmitido caso haja degradação do canal)
- 2 Active Queue Management: Melhora desempenho do TCP (Controlled Delay [CoDel] e Drop-Tail[padrão LTE], além dos disponíveis no NS-3)



Dual Connectivity Extension

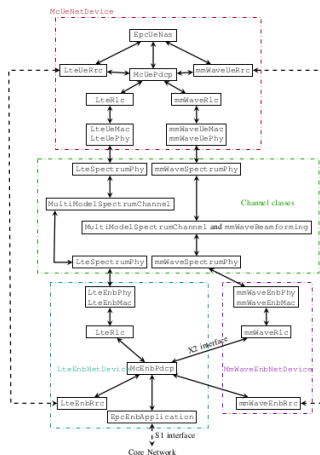


Figure 8: Block diagram of a dual-connected device, an **LTE eNB** and a **mmWave eNB** [29].



Use Cases

- A. Simulation Setup Walk-through
- B. Multi-User Scheduling Simulation
- C. Latency Evaluation for variable and Fixed TTI schemes
- D. TCP performance over mmWave
- E. LTE Aided Multi connectivity



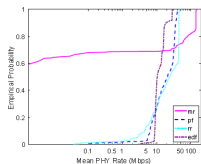
Módulo mmWave NS3 - Simulation Setup Walk-through

- 1** Definir os Atributos (mmWaveAttributesList)
- 2** Configurar o objeto MmWaveHelper
 - 1** Objetos Referentes aos canais
 - 2** MmWavePhyMacCommon Object
 - 3** Instal mmWave Stack on NS-3 nodes
 - 4** Attach UE to eNB
 - 5** Enable/Disable simulation Traces
 - 6** MmWavePointToPointEpcHelper
 - 7** Demais protocolos (por exemplo TCP/IP)
- 3** Definir Posições iniciais, Velocidades e Obstáculos
 - 1** MobilityHelper
 - 2** Buildings e BuildingsHelper
- 4** Setup Applications
- 5** Executar simulação utilizando Simulator

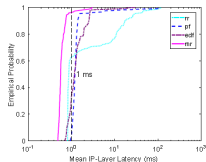


Ex.: Simulação de Escalonamento Multi-Usuário

Verificar a Latência e o Throughput dos usuários de uma célula com 1GHz de Banda

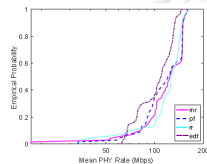


(a) Empirical CDF of rate

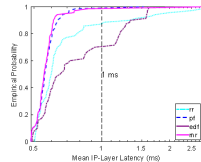


(b) Empirical CDF of latency

Figure 9: Distributions of PHY-layer throughput and IP-layer latency for 70 UEs, 10 Mbps/UE arrival rate



(a) Empirical CDF of rate

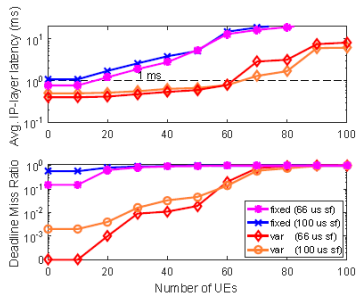


(b) Empirical CDF of latency

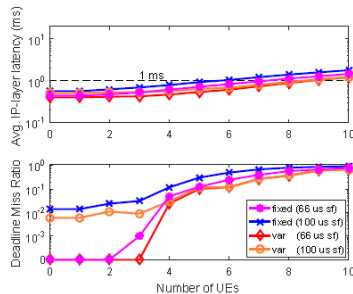
Figure 10: Distributions of PHY-layer throughput and IP-layer latency for 7 UEs, 100 Mbps/UE arrival rate

Ex.: Análise de Latência para TTI fixo e TTI variável

Verificar o efeito dos intervalos de transmissão variáveis e fixos na latência dos usuários



(a) 10 Mbps per UE arrival rate (100-bytes packets)



(b) 100 Mbps per UE arrival rate (1200-bytes packets)

Figure 11: Latency and Deadline Miss Ratio as a function of the downlink IP-layer arrival rate for fixed and variable TTI radio frame structures.

Ex.: Performance do Protocolo TCP sobre um canal mmWave

Verificar o desempenho do protocolo TCP com diferentes técnicas de Active Queue Management (AQM) (Drop-Tail ou Controlled Delay [CoDel])

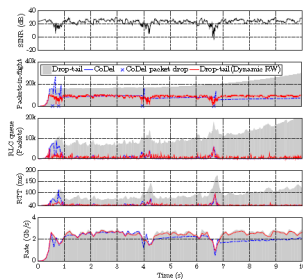


Figure 12: TCP performance of a single UE with human blockages. ©[2017] IEEE. Reprinted, with permission, from [18].

Ex.: Multi-Connectividade com LTE

Teste de desempenho entre Dual-Connectivity e Hard Handover)
[mc-twoenbs.cc]

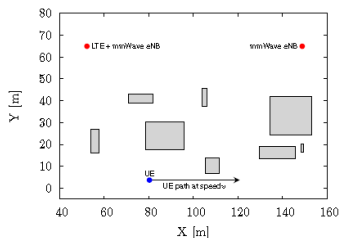


Figure 13: Random realization of the simulation scenario. The grey rectangles are randomly deployed non-overlapping obstacles.

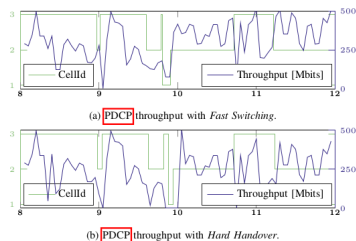



Figure 14: PDCP throughput with multiple RATs and eNBs. eNBs with CellId 2 and 3 are mmWave eNBs, while CellId 1 stands for the LTE eNB co-located with mmWave eNB 2.

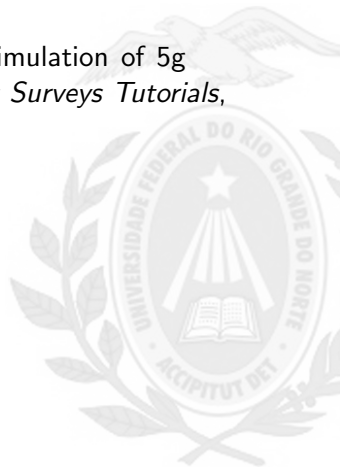
Potential Uses and Future Extensions

- 1 3GPP signaling/Beamtracking
- 2 Carrier Agregation
- 3 Virtual and Augmented reality Application
- 4 Multi-hop Architectures
- 5 Veicular Channel and traffic models
- 6 Public safety scenarios
- 7 Scalability
 - 1 Low-Rank Channel Modeling
 - 2 Migration to Cluster computing
- 8 Merge mmWave module with main ns-3 release



Referências

 MEZZAVILLA, M. et al. End-to-end simulation of 5g mmwave networks. *IEEE Communications Surveys Tutorials*, p. 1–1, 2018.



Agradecimentos

Agradeço a todos.

