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A Tutorial on Trace-based Simulations of MANETs on the Example of Aeronautical Communications

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Agenda

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- System Model.
  - Trace-based Mobility.
  - Trace-based Data Traffic.
  - Trace-based Radio Model.
  - Idealized Time-Division Multiple Access (TDMA) Medium Access.
- Simulation Scenario & Results.
- Conclusion.

- L-band Digital Aeronautical Communications System (LDACS) Air-to-Air (A2A) communication involves Air Traffic Control (ATC) and safety-related communication.
- Requirements (e.g., latency and reliability) are fixed, and message generation is clearly defined.

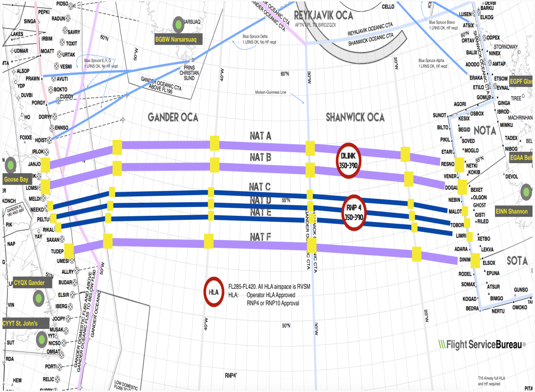

Figure 1: North Atlantic for the westbound traffic of 24^{th} Feb 2017 (source: wikipedia)

Introduction

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- The message generation is thus *bound* to mobility (tightly controlled).
- Randomized user behavior is not the right model to evaluate this system's Key Performance Indicators (KPIs).
- Aim to show how the OMNeT++ simulator can effectively make use of trace data, so that future research with these specific requirements may benefit.

System Model

- Trace-based Mobility.
- Trace-based Data Traffic.
- Trace-based Radio Model.
- Idealized TDMA Medium Access.

Trace-based Mobility

- Trace-based mobility is implemented in OMNeT++ through `BonnMotionMobility`.
- Aircraft mobility traces are converted to this format.
  $\Rightarrow$ in each line the coordinates (x, y, z) of a specific aircraft at time t.
- `ScenarioManager` is used to create and shutdown nodes in the scenario.

Trace-based Data Traffic

- An aircraft may trigger the generation of a message based on, e.g., entering an Oceanic Control Area (OCA), a different flight phase, etc.
  $\Rightarrow$ data traffic generation is linked to mobility

- A novel `UdpTraceBasedApp` inherits from `UdpBasicApp` (requires an additional trace file).

- The `UdpBasicApp`'s `startTime`, `stopTime` and `sendInterval` parameters are ignored $\Rightarrow$ expects a text file that contains a simulation time stamp in each line.

Triggering time
t_1
t_2
$\dots$
t_n

Table 1: A tabular presentation of the contents of a trace file.

- These trace files are generated jointly with the mobility trace files (to link mobility to message generation).
- May have different destinations or message sizes.

Idealized TDMA Medium Access

- Large communication ranges prevent CSMA/CA-like Medium Access Control (MAC) protocols.
  - The actual MAC protocol for LDACS A2A is therefore a TDMA-based protocol. $\Rightarrow$ as LDACS Air-to-Ground (A2G) [1], [2].
- Routing plays a major role in LDACS A2A.
  - before the proposed MAC protocol was sufficiently specified and implemented.
  - to focus on the effects of routing protocols in isolation of the underlying MAC.

$\Rightarrow$ an *idealized* TDMA protocol was required.

Idealized TDMA Medium Access

- A novel `TdmaMac` implementation in OMNeT++.
- Allocates time slots to users unrealistically through an oracle $\Rightarrow$ without any control overhead.
- A global `TdmaScheduler` entity $\Rightarrow$ Users are equipped with a custom Network Interface Card (NIC) that provides a `TdmaMac` sublayer.

Idealized TDMA Medium Access

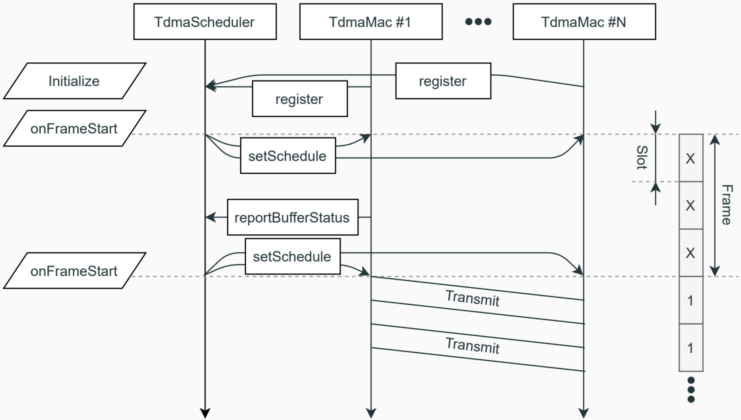

Figure 2: Flow chart of the provided idealized TDMA MAC protocol.

Trace-based Radio Model

- The computation complexity of realistic channel modeling. (evaluating the model for hundreds of users over real-world hours).

- A simplified and averaged model to represent different Physical (PHY) layer aspects.

- A novel `TraceBasedRadio` model has been implemented, which extends the `UnitDiskRadio` model.
  - A trace file maps Signal-to-Noise Ratio (SNR) to a priori computed Packet Error Rate (PER) and Bit Error Rate (BER).

Trace-based Radio Model

- The SNR is found similarly to what is done in [3]:
  - Obtaining the Free-Space Path Loss (FSPL) denoted by $L_p(d, f)$
    $d :=$ the distance between the transmitter and the receiver
    $f :=$ the transmission frequency

$$L_p(d, f)\,[\mathrm{dB}] = 20\log_{10}(d\,[\mathrm{km}]) + 20\log_{10}(f\,[\mathrm{MHz}]) + 32.4478\,[\mathrm{dB}]. \quad (1)$$

  - Calculating received power P_{rx}
    $P_{\text{tx}} :=$ the transmission power.
    $G_{\text{tx}}, G_{\text{rx}} :=$ the transmitter and receiver gains.
    $L_{\text{tx}}, L_{\text{rx}} :=$ the transmitter and receiver losses.

$$P_{\text{rx}}\,[\mathrm{dBm}] = P_{\text{tx}}\,[\mathrm{dBm}] + G_{\text{tx}}\,[\mathrm{dBi}] - L_{\text{tx}}\,[\mathrm{dB}] + G_{\text{rx}}\,[\mathrm{dBi}] - L_{\text{rx}}\,[\mathrm{dB}] - L_p(d, f)\,[\mathrm{dB}] \quad (2)$$

Trace-based Radio Model

- The SNR is found similarly to what is done in [3].

  F_N := the noise figure

  N_0 := the thermal noise density

  B := the receiver bandwidth.

$$\text{SNR}\,[\text{dB}] = P_{\text{rx}}\,[\text{dBm}] - \left(F_N\,[\text{dB}] + N_0\left[\frac{\text{dBm}}{\text{Hz}}\right] + 10\log_{10} B\,[\text{Hz}]\right) \qquad (3)$$

- A provided `TraceBasedReceiver` extends the `UnitDiskReceiver` model by performing this computation, and passing the SNR to a novel `TraceBasedErrorModel`.

- `TraceBasedErrorModel` uses a trace file (lookup table) to obtain the closest-matching SNR's mapping to a PER.

Validation Scenario

- The receiver at $(x = 0\,\mathrm{km}, y = 0\,\mathrm{km}, z = 30\,\mathrm{km})$.
- The transmitter at $(x \in \{180, 220, 275, \ldots, 1400\}\,\text{km}, y = 0\,\mathrm{km}, z = 30\,\mathrm{km})$.
- The distances are chosen to reflect the entire range from certain success to certain failure.

SNR [dB]	PER	BER	SNR [dB]	PER	BER
-5	1	0.5	3	0.75	0.18
-4	1	0.5	4	0.7	0.15
-3	1	0.49	5	0.6	0.13
-2	1	0.485	6	0.5	0.073
-1	1	0.475	7	0.3	0.04
0	1	0.47	8	0.1	0.02
1	1	0.465	9	0.05	0.006
2	0.95	0.39	10	0.01	0.0012

Table 2: The SNR to PER and BER lookup table.

Trace-based Radio Model

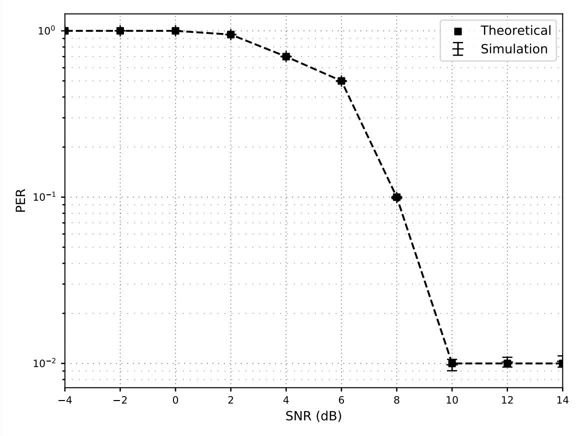

Figure 3: A validation scenario compares expected PER to the one observed through simulation using the provided trace-based radio model.

Simulation Scenario

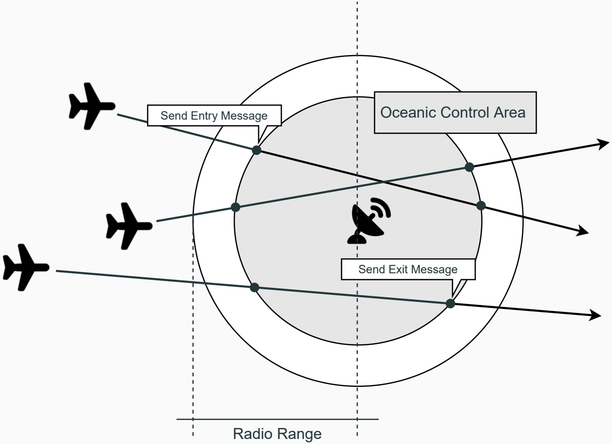

Figure 4: Evaluation Scenario

Simulation Scenario

Number of users	$n \in \{100, 200, \dots, 500\}$
MAC	Idealized TDMA
TDMA slot duration	$10\,\mathrm{ms}$
TDMA number of slots	10 slots
TDMA retransmission attempts	0
Radio model	`traceBasedRadioModel`
Radio range	$400\,\mathrm{km}$
OCA range	$370.4\,\mathrm{km}$
Number of runs	10
Simulation time	$10\,000\,\mathrm{s}$

Table 3: Simulation parameters of the exemplary aeronautical Mobile Ad-hoc Network (MANET) scenario.

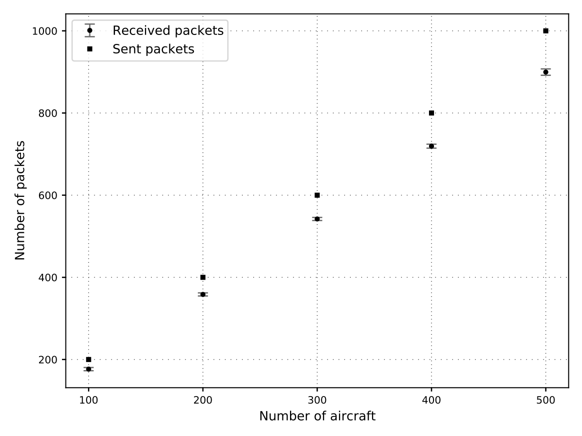

Figure 5: The number of received packets with different number of aircraft considered in the scenario.

Conclusion

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- Trace-based simulation has been motivated by the evaluation of LDACS A2A.
$\Rightarrow$ abundant real-world data is available (simulating a communication system under realistic circumstances).

- A novel data traffic application that links the mobility data and the generation of messages is presented.

- An idealized TDMA MAC protocol that fills a gap in the OMNeT++ toolbox. $\Rightarrow$ suitable for simulations where effects of a full-fledged MAC should be suppressed.

- The implementation of a trace-based radio model for the OMNeT++ simulator is done to include realistic radio channel modelling.

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Conclusion

- All implemented modules are available in [4, 5, 6, 7] under open licenses in such a way that benifits the future research into trace-based scenarios.

- In future work, the trace-based radio model: should support BER instead of just the PER, and it should work with Signal-to-Interference-plus-Noise Ratio (SINR) instead of just SNR.
    - an extension to a radio model that understands multiple, orthogonal frequency channels.

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[1] U. Epple, M. Schnell, G. A. Center (DLR), and Germany, "Overview of Interference Situation and Mitigation Techniques for LDACS," in *IEEE/AIAA 30th Digital Avionics Systems Conference*. IEEE.

[2] U. Epple, F. Hoffmann, and M. Schnell, "Modeling DME interference impact on LDACS1," in *2012 Integrated Communications, Navigation and Surveillance Conference*. IEEE, pp. G7–1.

[3] M. A. Bellido-Manganell and M. Schnell, "Feasibility of the Frequency Planning for LDACS Air-to-Air Communications in the L-band."

[4] M. A. Eltayeb Ahmed, "Code Release for UdpTraceBasedApp," Hamburg University of Technology, Institute of Communication Networks. [Online]. Available: https://github.com/ComNetsHH/UDPTraceBasedApp

[5] K. Fuger, "Code Release for TDMA MAC," Hamburg University of Technology, Institute of Communication Networks. [Online]. Available: https://github.com/ComNetsHH/omnet-tdma

[6] F. Khan, "Code Release for Trace Based Radio Model," Hamburg University of Technology, Institute of Communication Networks. [Online]. Available: https://github.com/ComNetsHH/Trace-Based-Radio-Model

[7] M. A. Eltayeb Ahmed, "Code Release for Trace-based Simulations of Mobile Ad-hoc Networks on the Example of Aeronautical Communications," Hamburg University of Technology, Institute of Communication Networks. [Online]. Available: https://github.com/ComNetsHH/MANET-Trace-Based-Simulations