

Effect of ADS-B Characteristics on Airborne CD&R

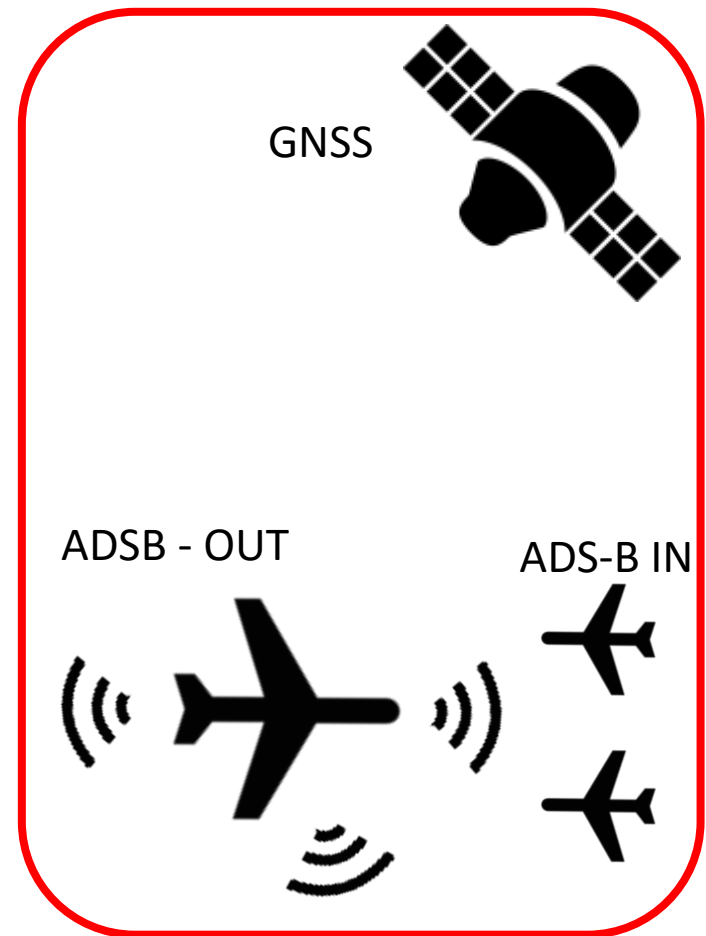
SID Presentation
T.P. Langejan,
9th of November, 2016

Presentation overview

- Introduction
- Research motivation
- ADS-B model
- Simulations
- Results

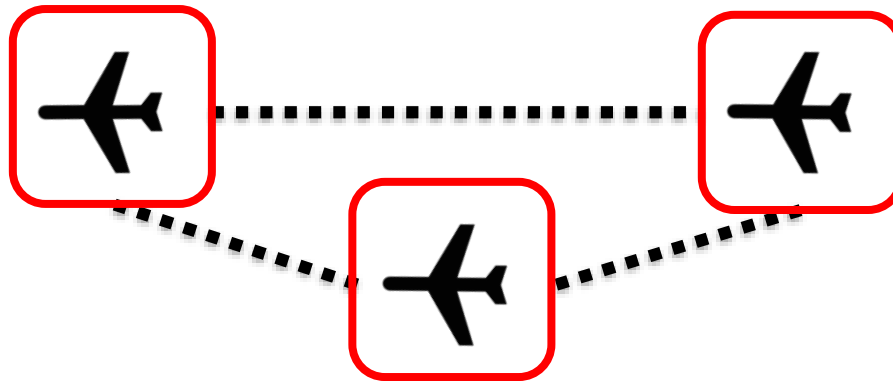
ADS-B – Overview

- Transmit state information
 - Omnidirectional
 - Specific update rate
 - Different reports
-
- Focus on Airborne System



Research Motivation

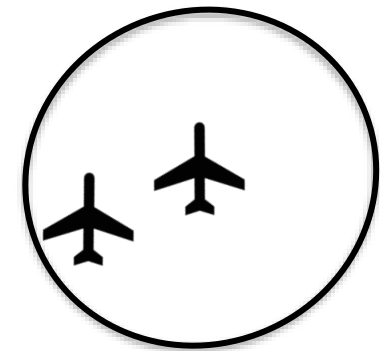
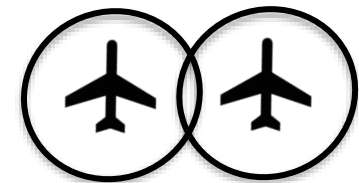
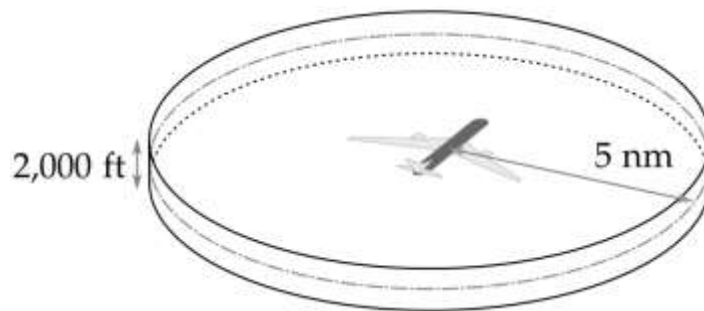
- Decentralized Control
- Airborne separation



- Airborne Conflict Detection & Resolution (CDR)
 - MVP method
- **ADS-B IN/OUT Data Link**

Separation minima

- For en-route air traffic
 - 5 NM horizontal plane
 - 1000 ft vertical plane
- Loss of separation/Intrusion



Demo – Super 8

- 2.5 NM IPZ

Perfect



ADS-B



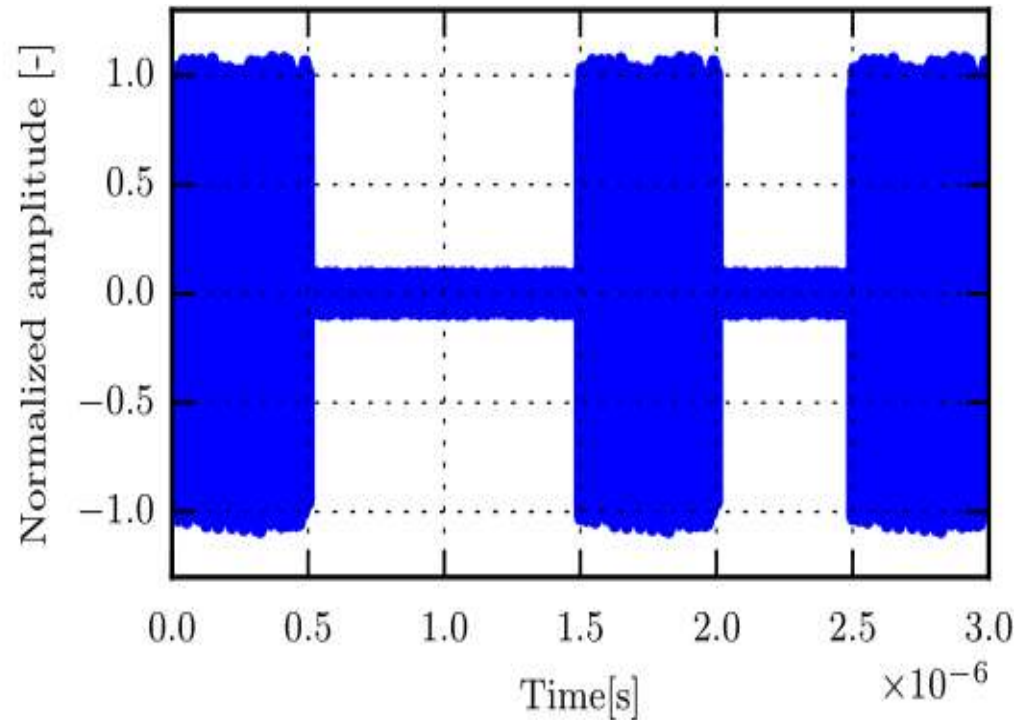
Research objective

Study the effect of ADS-B limitations and inaccuracies on tactical CDR methods for en-route traffic.

- Which factors affect the quality of state information in the ADS-B system?
- How severe is the effect of ADS-B limitations and inaccuracies on CDR performance?
 - What is the most dominant factor

ADS-B Signal

- 1090 MHz
- Specific length: 120 μs
- PPM
- Transmit rate: ~ 2 Hz



ADS-B - Limitations

- State accuracy
- Truncation
- Latency
- Transmit rate
 - Use of “old” information
 - Non synchronous for all aircraft

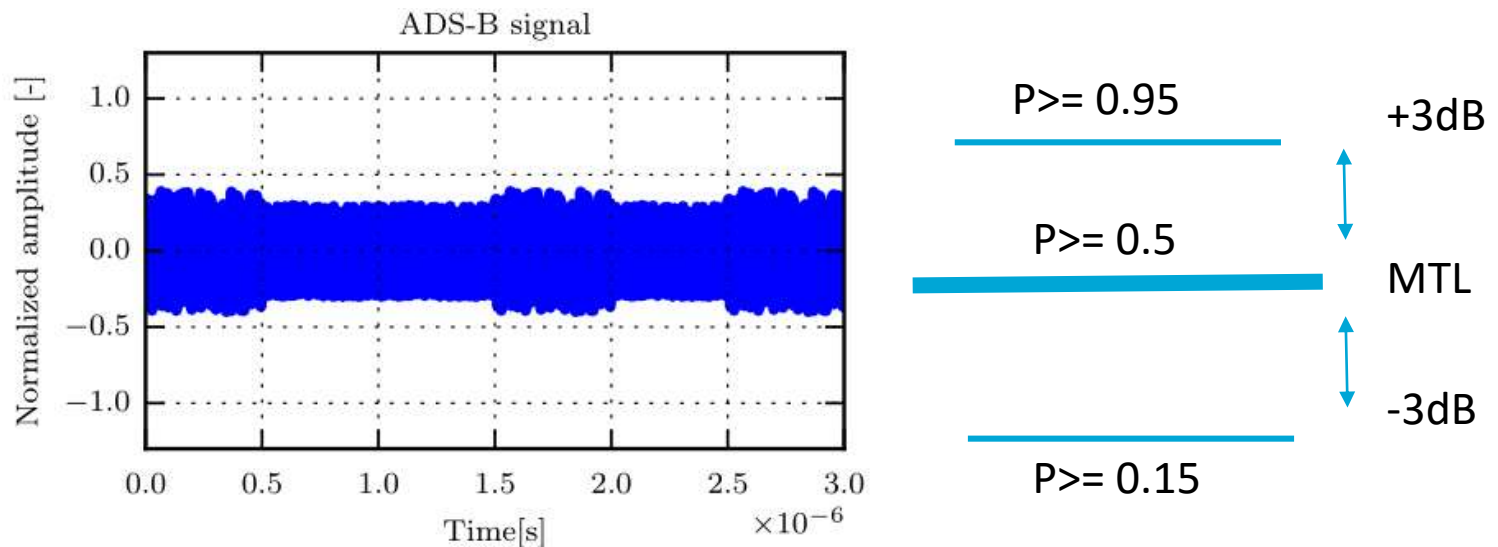
System
related

- Detect and Decode Probability
 - Distance
 - Interference

Situation
related

ADS-B Model – Range

- Based on MOPS ⁹
- Mean Triggering Level (MTL)
 - Detect and Decode probability¹⁰



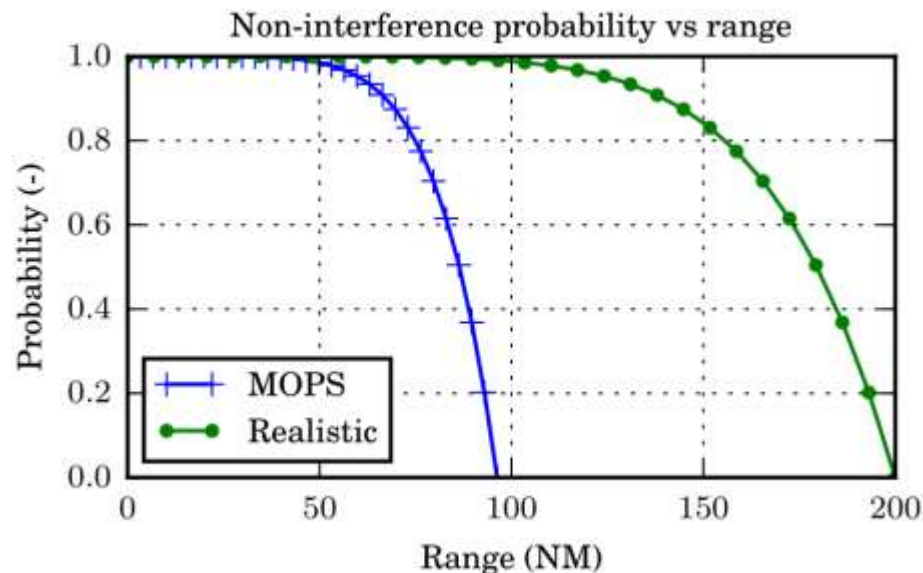
9. RTCA, 2002

10. W. Chung et al, 2006

ADS-B Model – Range

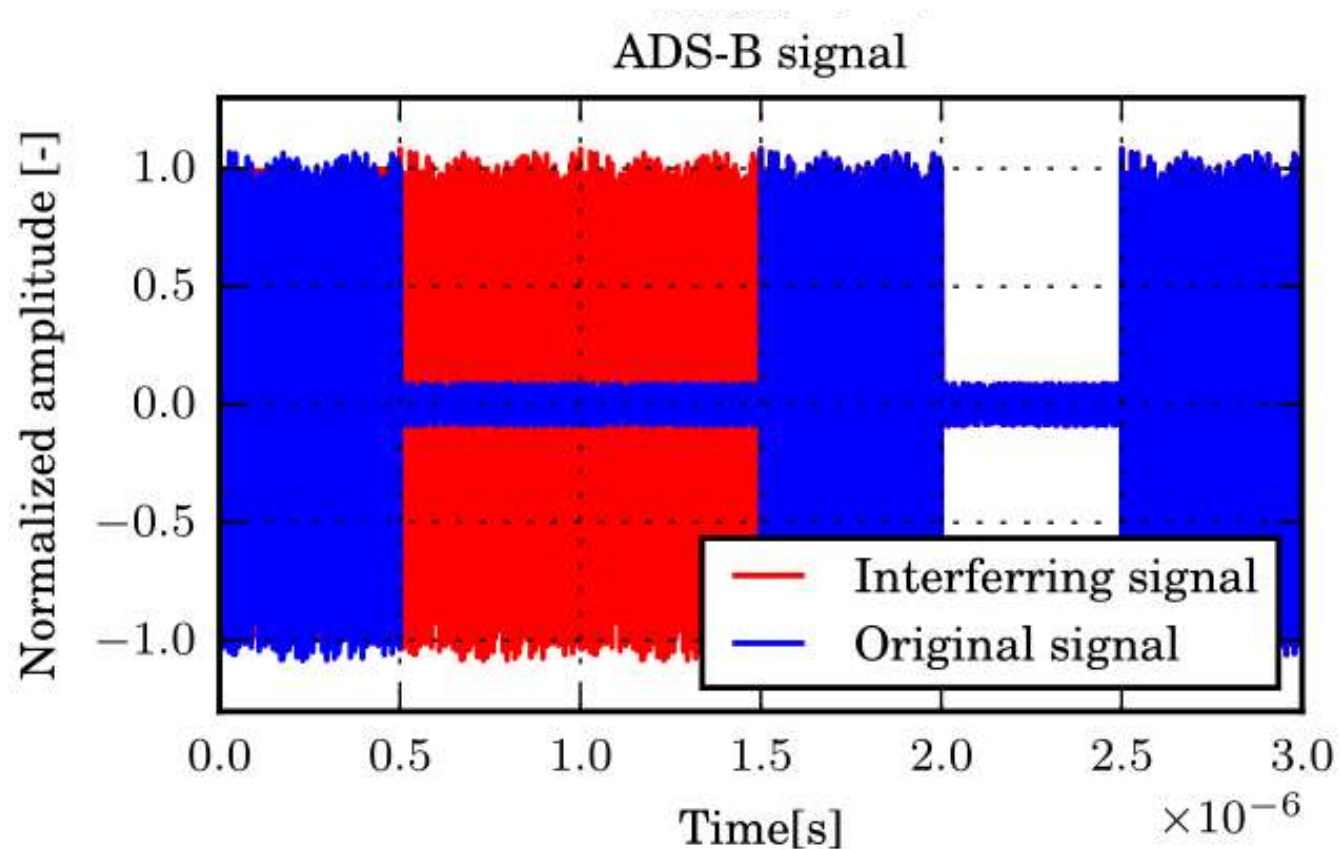
- Free Space Path Loss (FSPL)
- Fixed Transmit Power
- Rewrite for Probability¹⁰

$$P(r) = 1 - \left(\frac{r}{r_0}\right)^k, r \geq r_0$$



10. W. Chung et al, 2006

ADS-B Model – Interference



ADS-B Model – Interference¹¹

$$P[X = k] = (\lambda t)^k \frac{e^{-\lambda t}}{k!}, k = 0, 1, 2, \dots$$

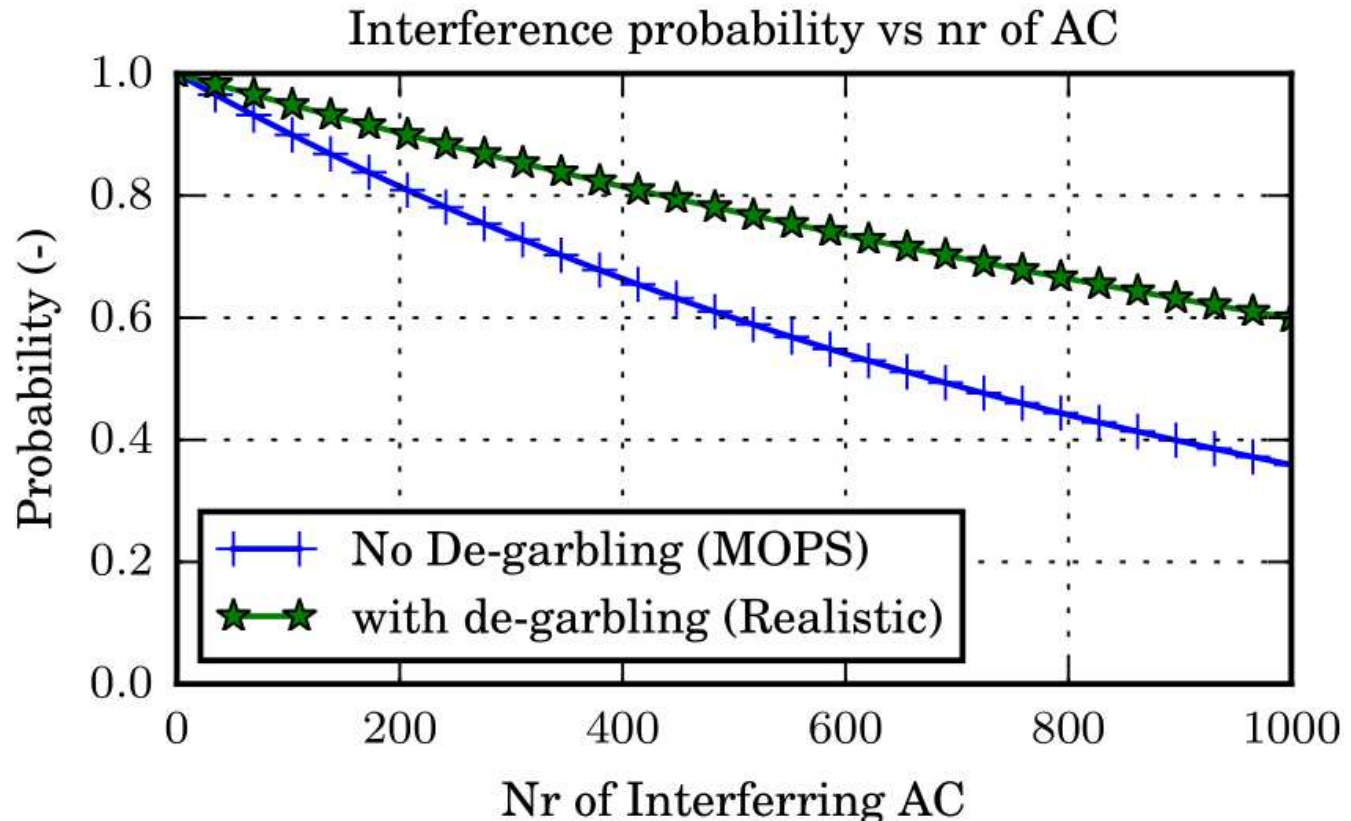


- λ = number of aircraft x ADS-B transmit frequency
- Probability of 0 other messages in a time interval of $120 \mu s$

$$P[X = 0] = (\lambda t)^0 \frac{e^{-\lambda t}}{0!} = e^{-N_{ac} \cdot F_{update} \cdot 120 \cdot 10^{-6}}$$

11. R. Barhydt et al., 2004

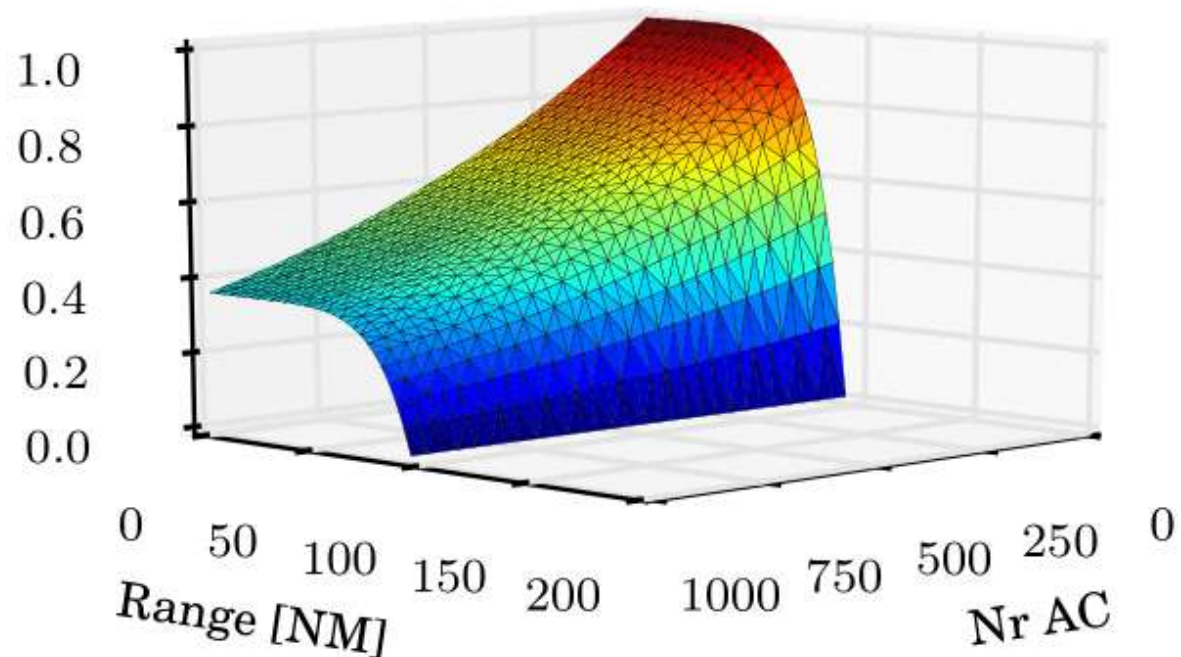
ADS-B Model – Interference



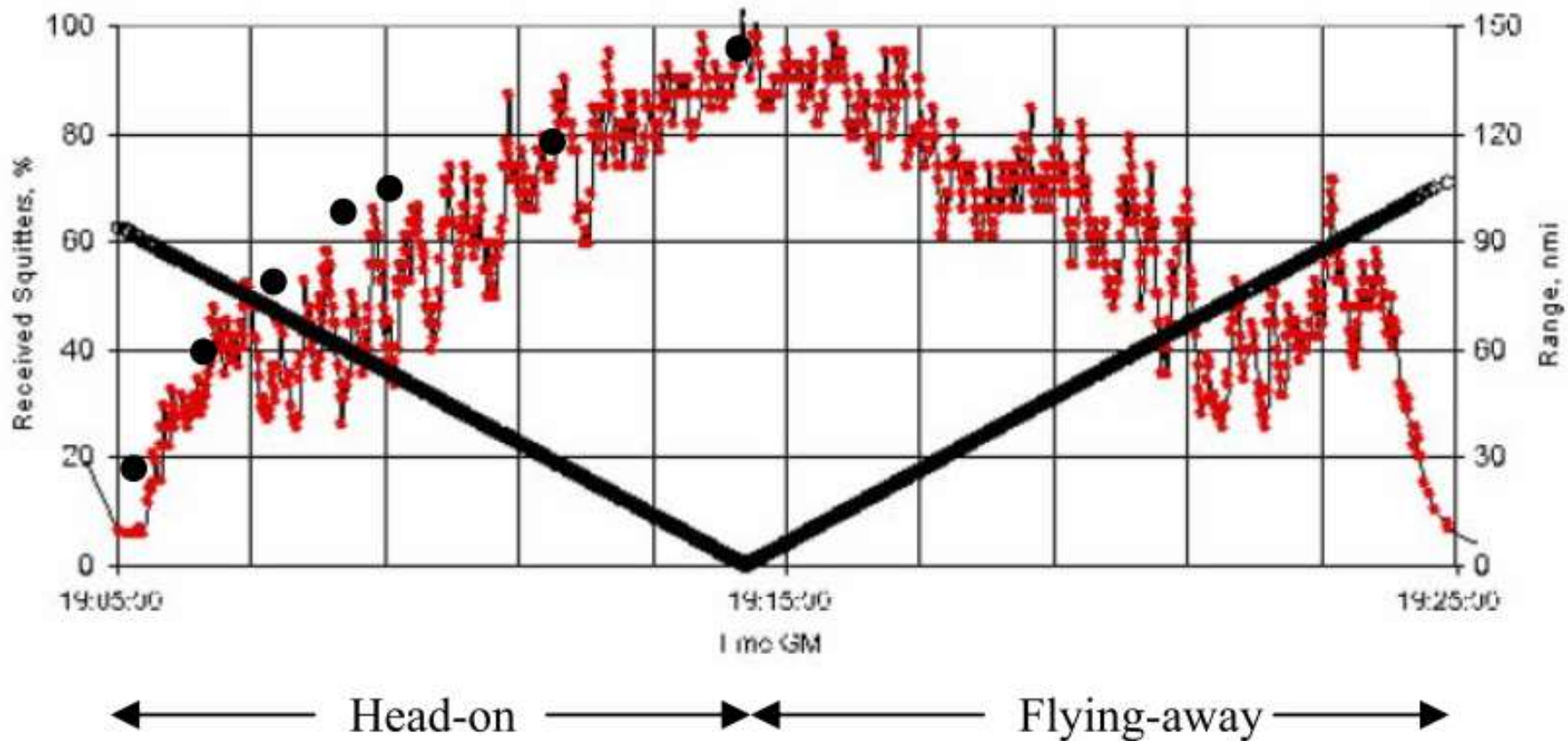
ADS-B Model – Situation related

$$\overbrace{P_{T(i,j)}(r, AC)}^{\text{Total probability}} = \overbrace{P_{R(i,j)}(r)}^{\text{Range}} \cdot \overbrace{P_{I(i,j)}(N_{acscaled})}^{\text{Scaled Interference}}$$

Reception and decoding probability



ADS-B Model – Validation¹²



12. Chung et al., 2006

Introduction

Motivation

ADS-B model

Simulations

Results

BlueSky Simulator

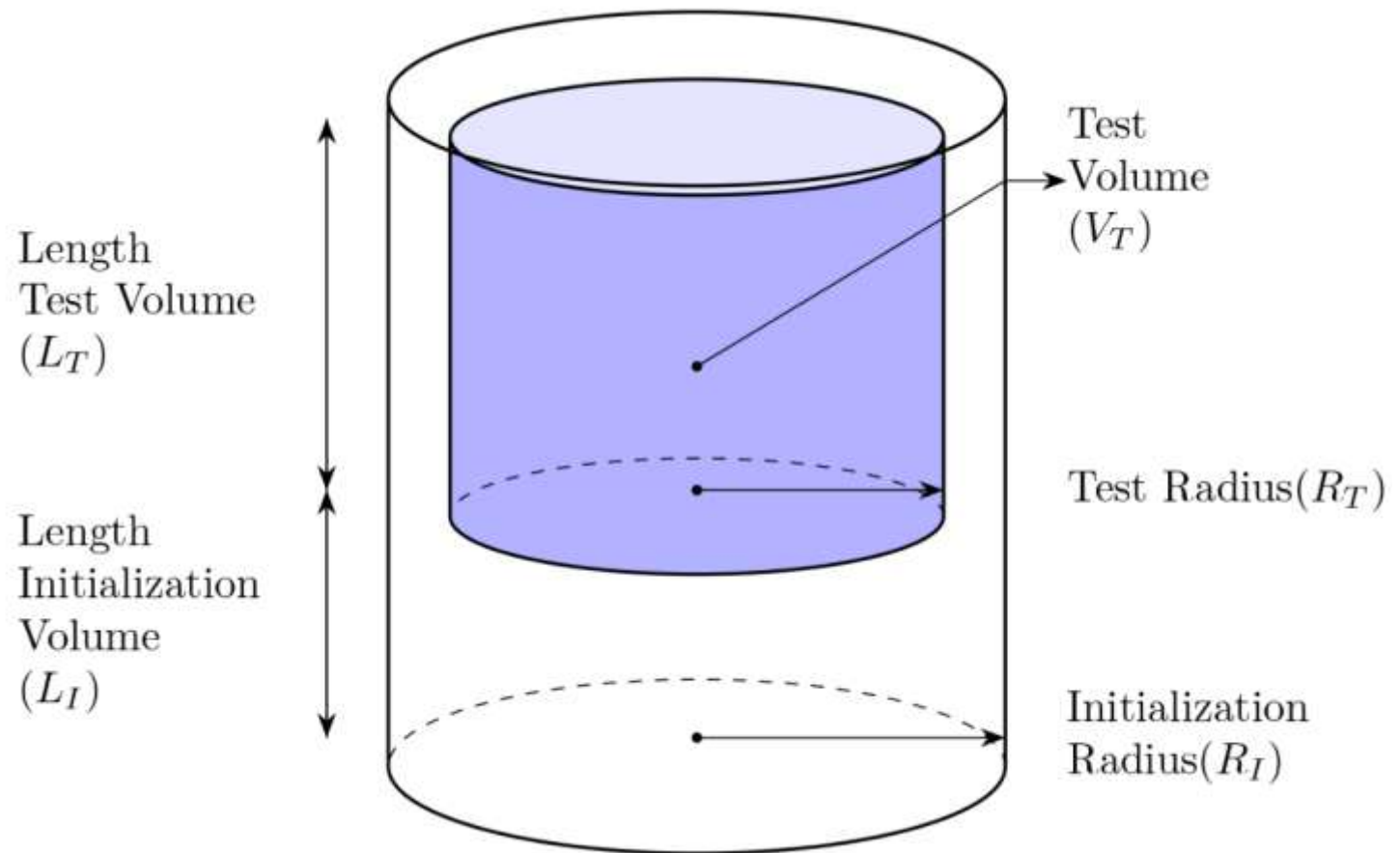


Demo – Super 8

- ADS-B implemented vs Perfect state information
 - 2.5 NM IPZ

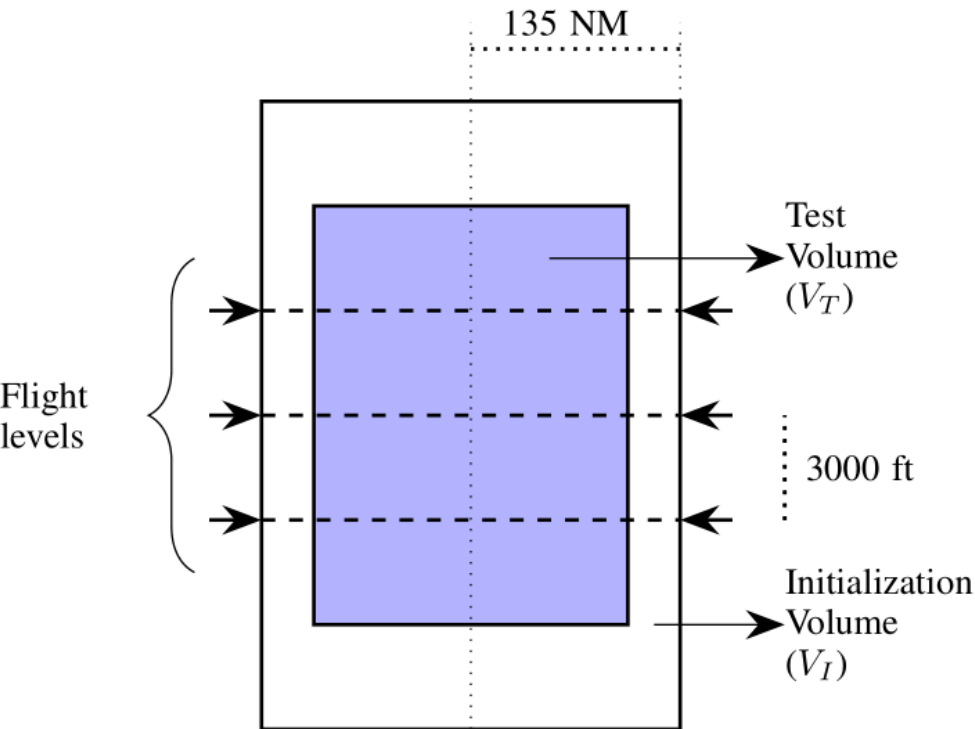


Simulations – Experiment design

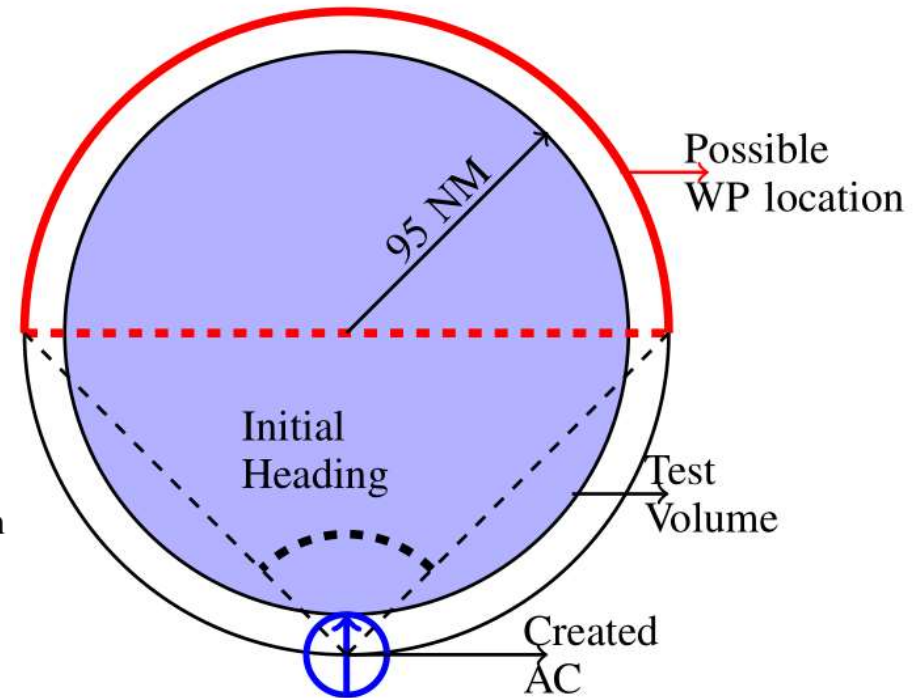


Simulations – Experiment design

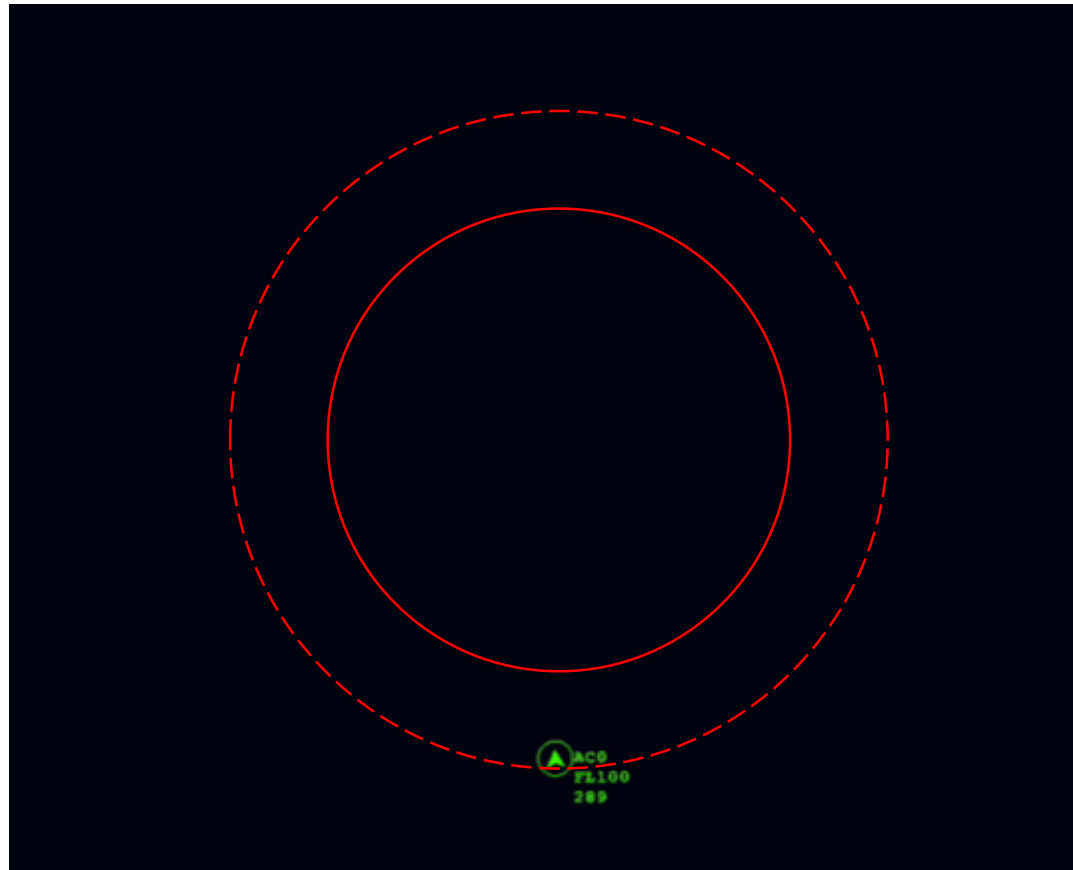
Side view



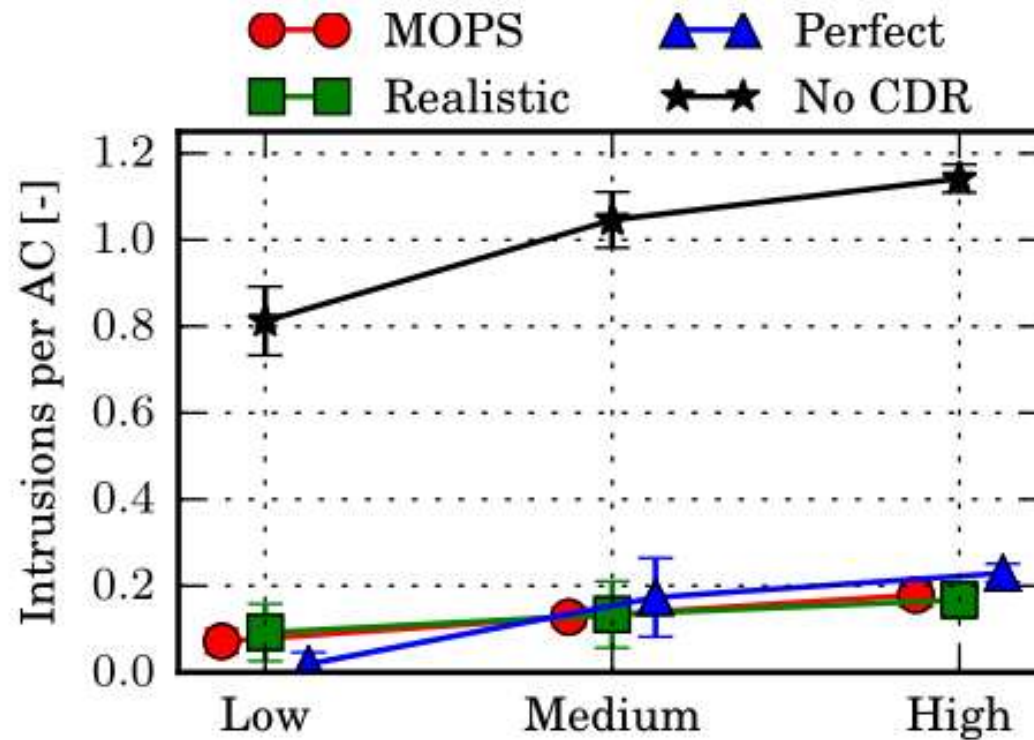
Top view



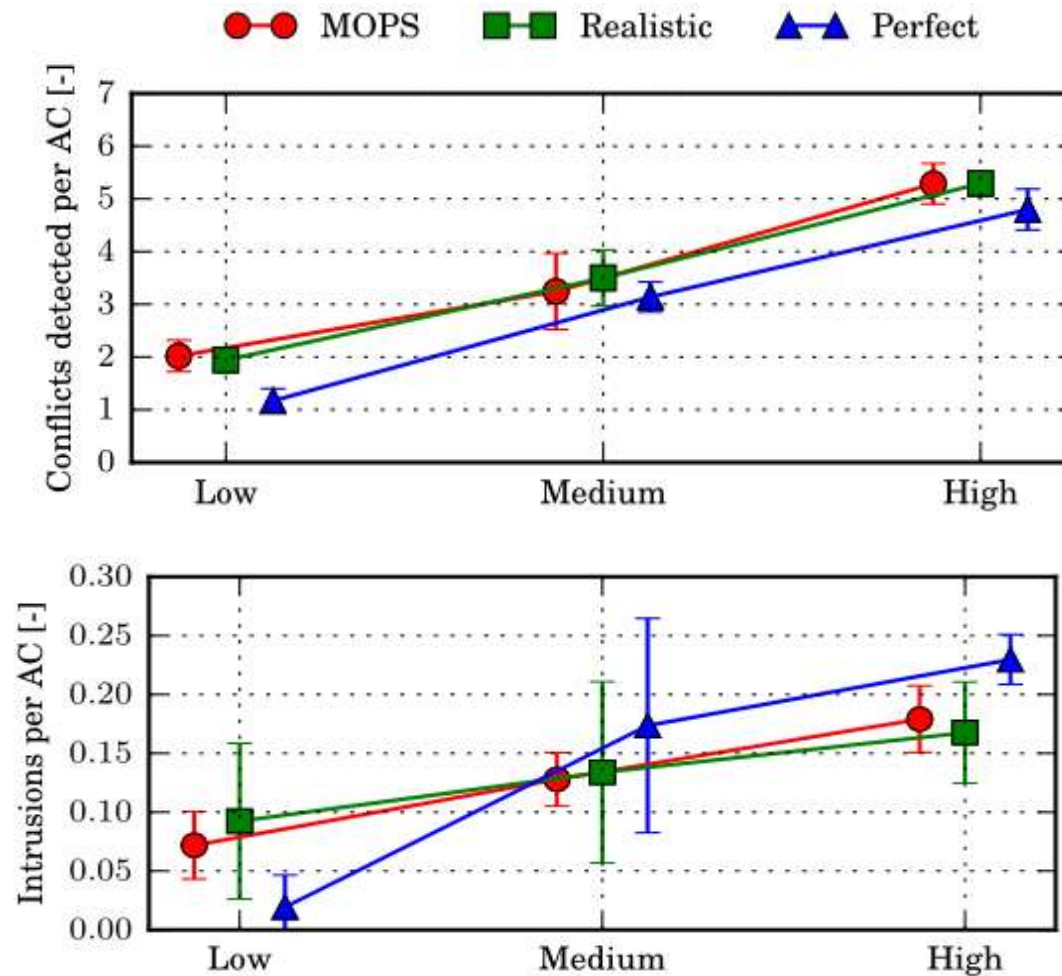
Simulations – Experiment DEMO



Results – Safety EXP I

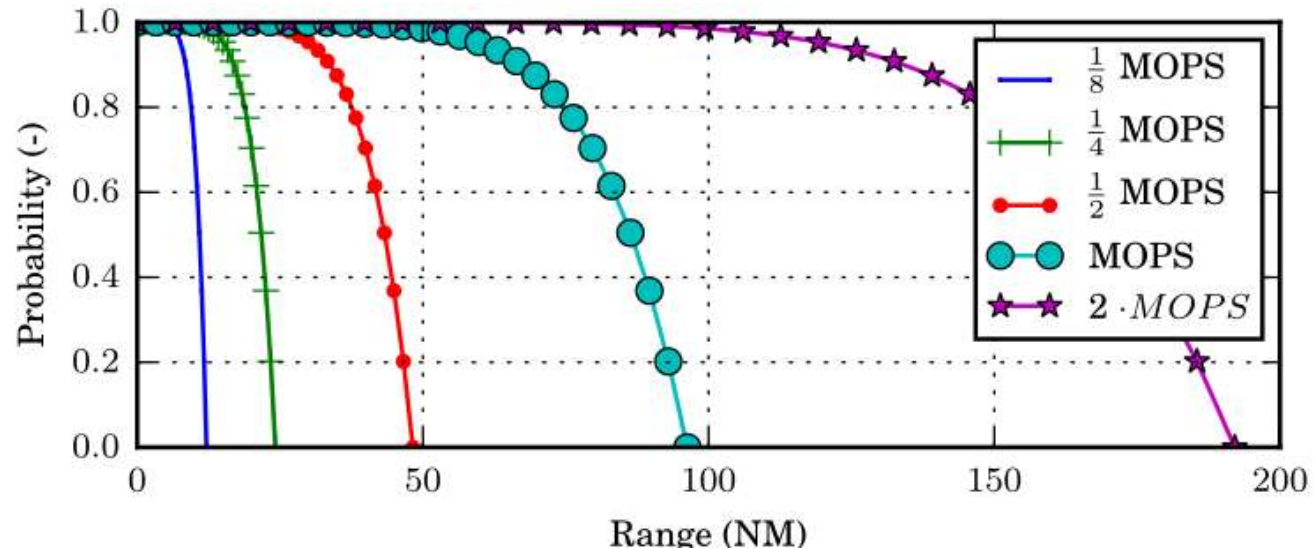


Results – Safety EXP I

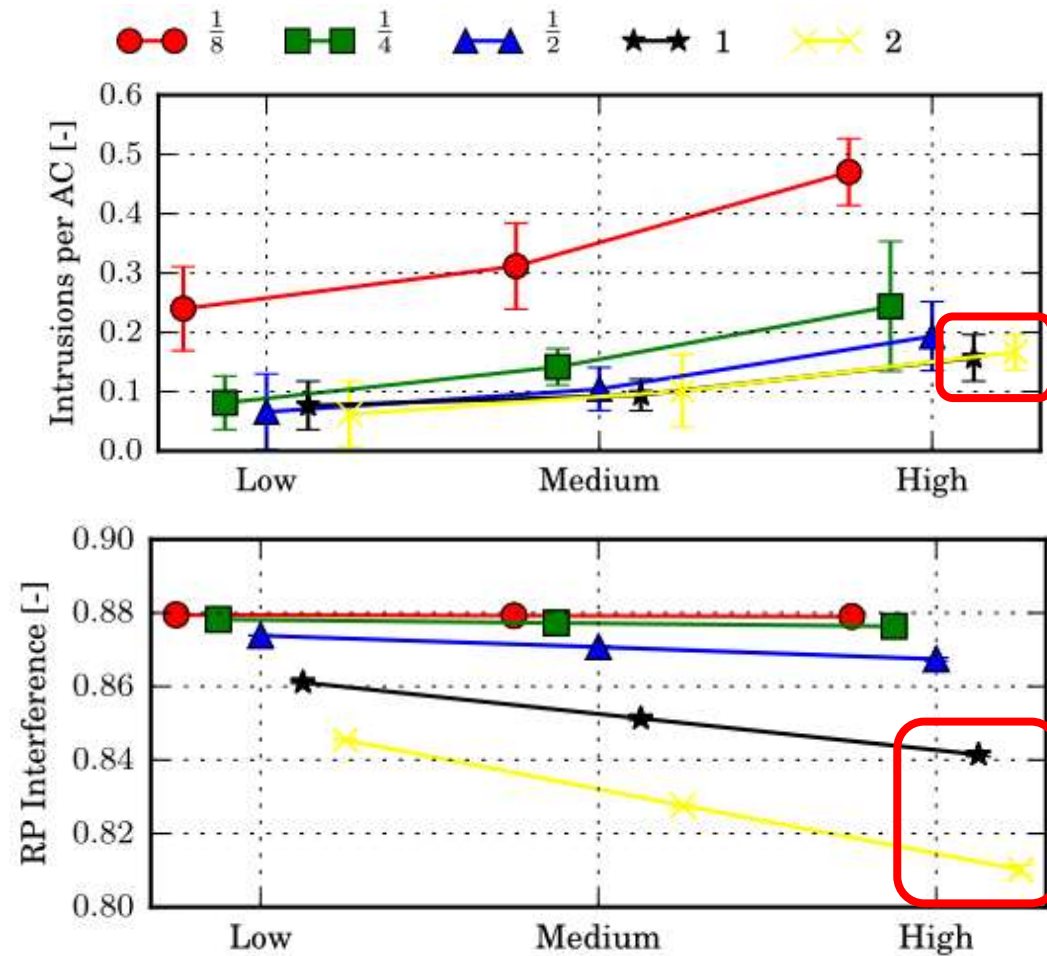


Simulations – EXP II

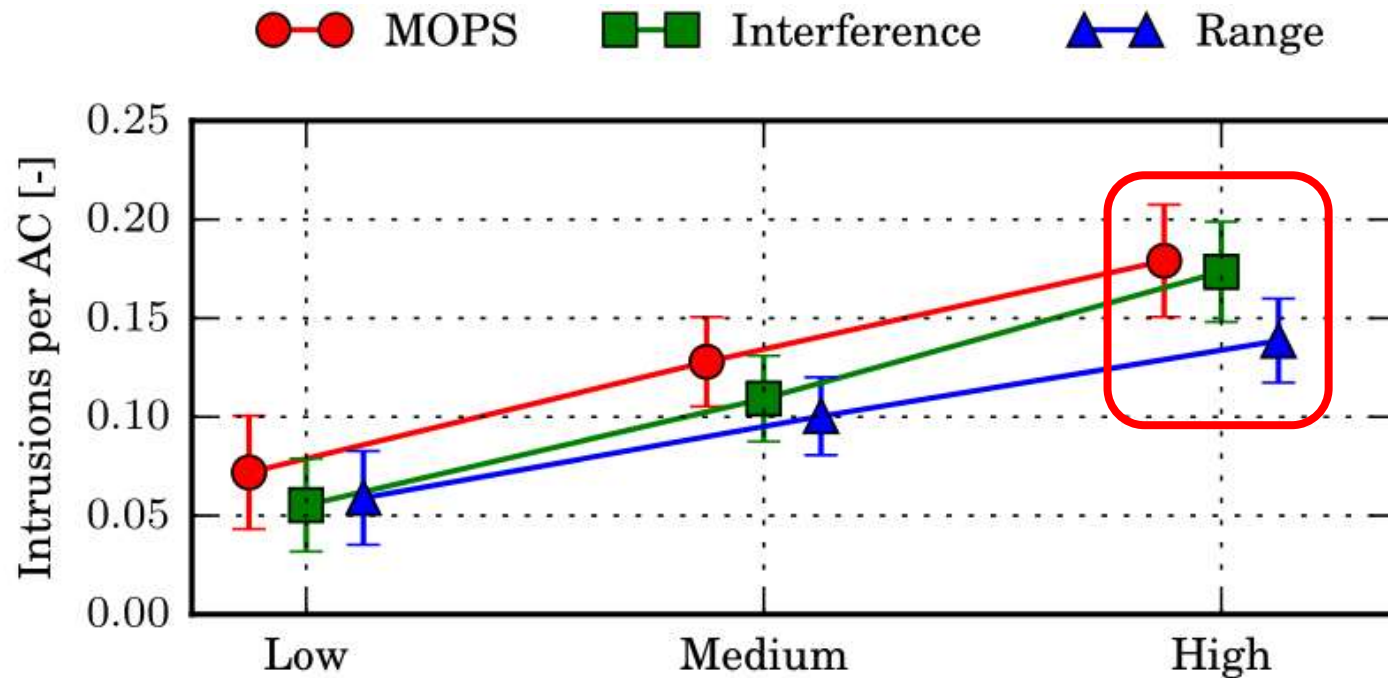
- **Range analysis**
 - Goal: Study effect of different reception ranges
 - Based on MOPS range



Results – Safety EXP II



Results – Safety EXP III

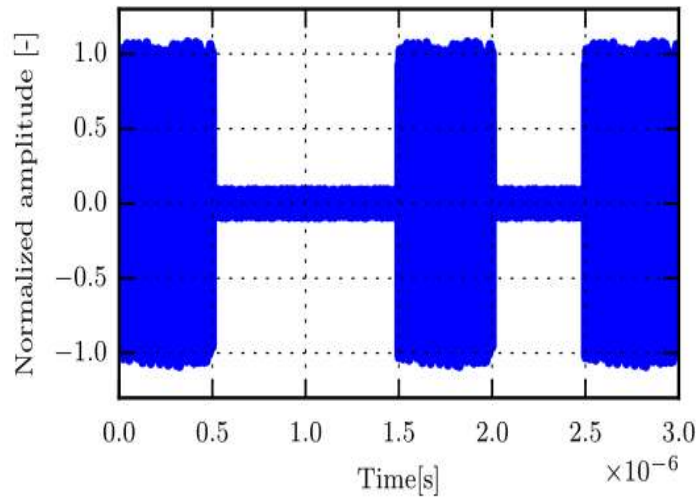


Conclusion

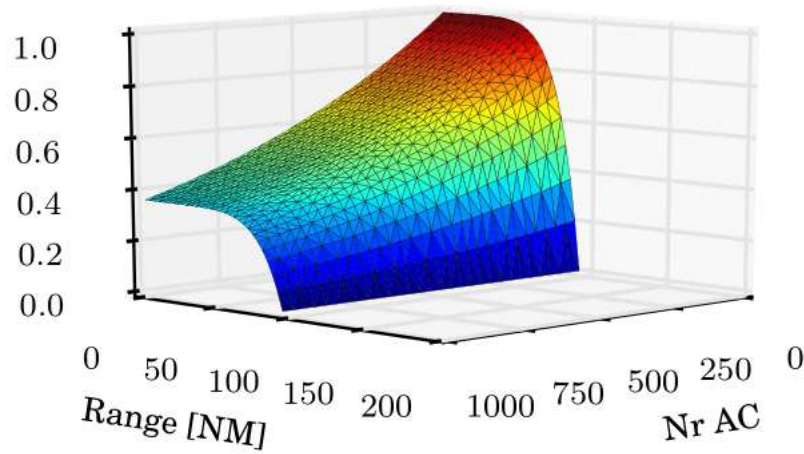
- ADS-B no direct threat to Free Flight
- MVP method is very robust
- Interference effect should be taken into account
 - Becomes more dominant at higher densities
- Increase in transmit power not per se beneficial
- Security of ADS-B system
- Implementation?



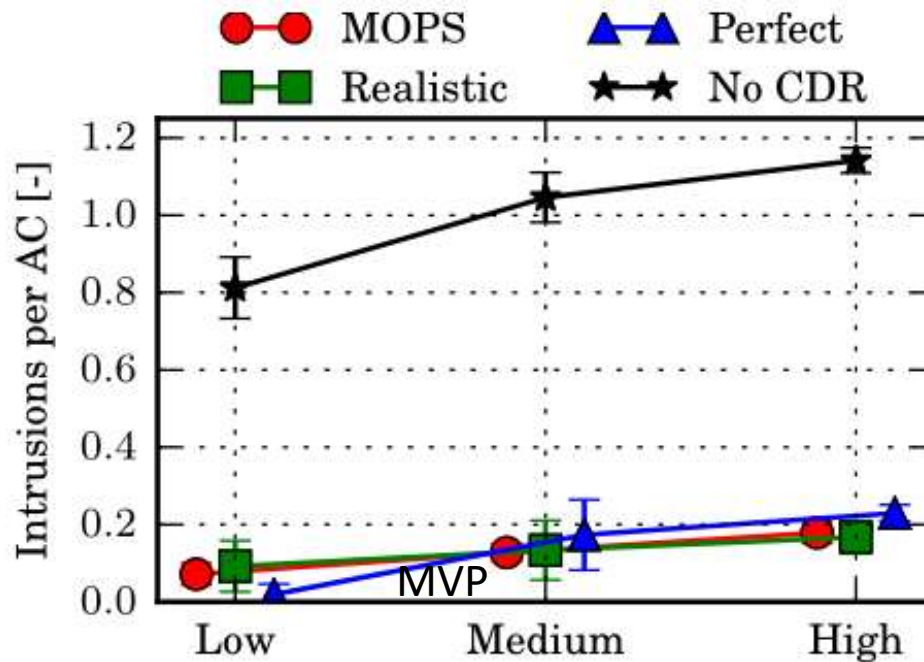
Questions



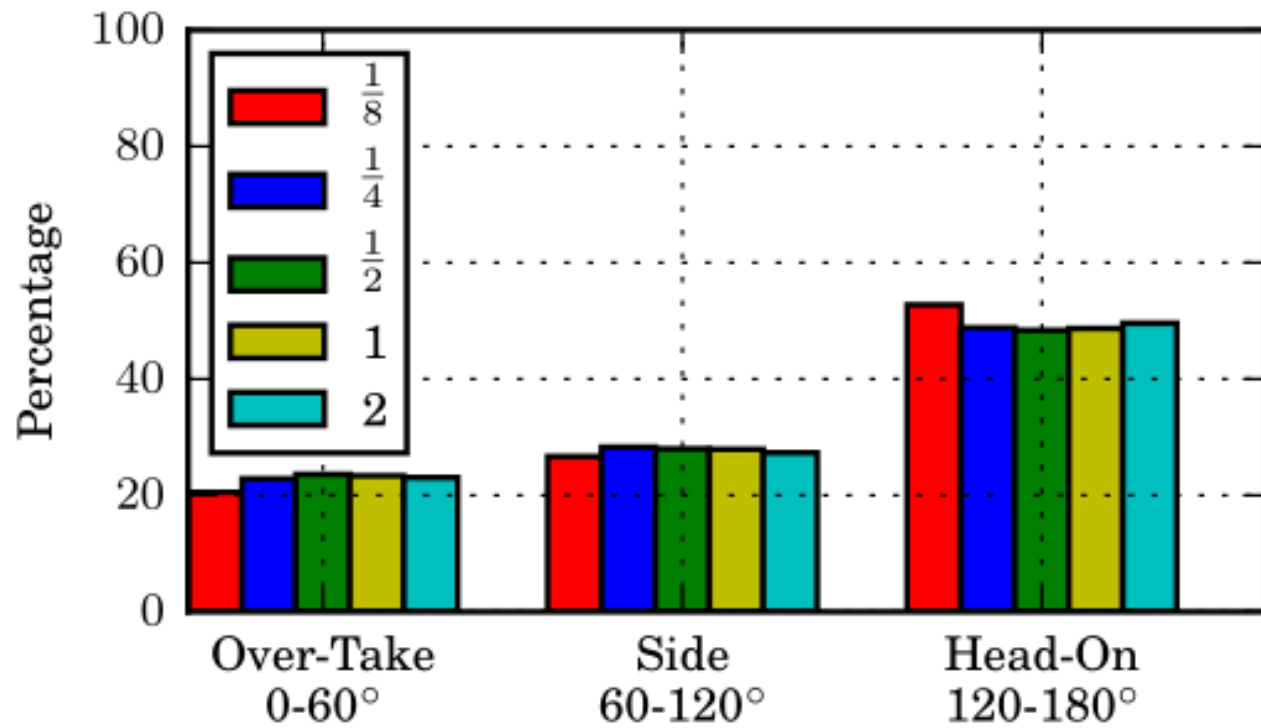
Reception and decoding probability



Results – Safety: Intrusions



Swarming



Experiment parameters

Table VII: Experiment Area settings

Experiment area dimensions	
Parameter	Value
Test Radius [NM]	95
Test Radius Area [NM^2]	57 255
Initialization radius [NM]	135
Δ flight levels [ft]	3 000
Number of flight levels [-]	3
Altitude middle flight level [ft]	10 000

Table VIII: Aircraft initialization variables

Parameter	Aircraft initialization properties	
	Distribution	Value
Initialization Location [$^\circ$]	Uniform	0-360
Initial Heading [$^\circ$]	Uniform	-45 - +45
Initial FL [FL]	Uniform	70, 100 or 130
Destination [FL]	Uniform	70, 100 or 130
True Air Speed [$\frac{m}{s}$]	Uniform	100-200
AC type [-]	-	B747

Aircraft Scenarios			
Parameter	Scenario names		
	Low	Medium	High
Steady state nr of AC [AC]	50	75	100
Steady state AC / 10 000 NM^2 FL [$\frac{AC}{NM^2}$]	2.8	4.4	5.6
AC create update interval [s]	42	31	21

Experiment parameters

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Experiment parameters

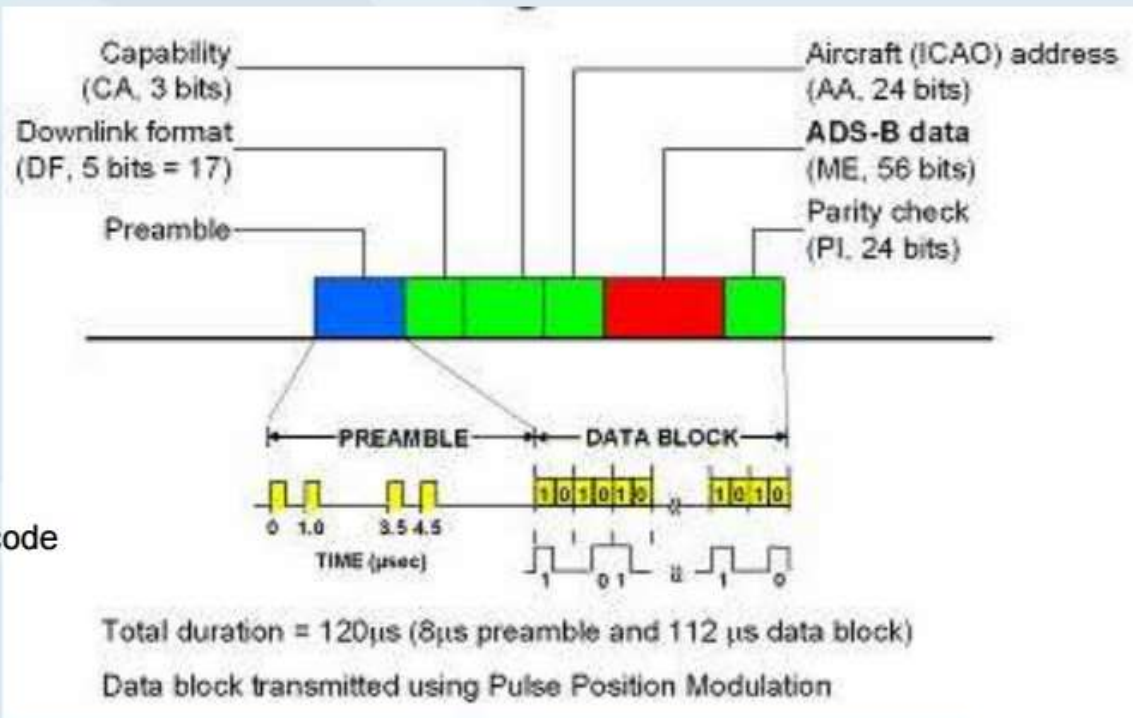
Table 4-3: Capacity limit for Schiphol airport, obtained from (Aviation, 2008).

Parameter/Model	Number of IFR flights per hour
Movements Arrival peak	106
Of which arrivals	68
Of which departures	38
Movements Departure peak	110
Of which arrivals	36
Of which departures	74

Experiment parameters

Extended Squitter Format

- **Preamble:** Allows synchronisation on reception
- **DF = Message type**
 - 11 Acq squitter
 - 17 ADS-B
 - 18 TIS-B
 - 19 Military
- **CA= subtype**
- **PI = error detection code**



ADS-B Model - Interference

ADS-B transmission rates:

- Airborne Position Squitter (2 Hz)
 - Surface Position Squitter (1 Hz)
 - Airborne Velocity Squitter (2 Hz)
 - Aircraft ID Squitter (0.2 Hz)
 - Operational State (0.4 Hz)
 - Target State (0.8 Hz)
- 
- 6.4 Hz

TCAS transmission rate: (4 Hz) 4 Hz

ADS-B message duration: 120 μ s

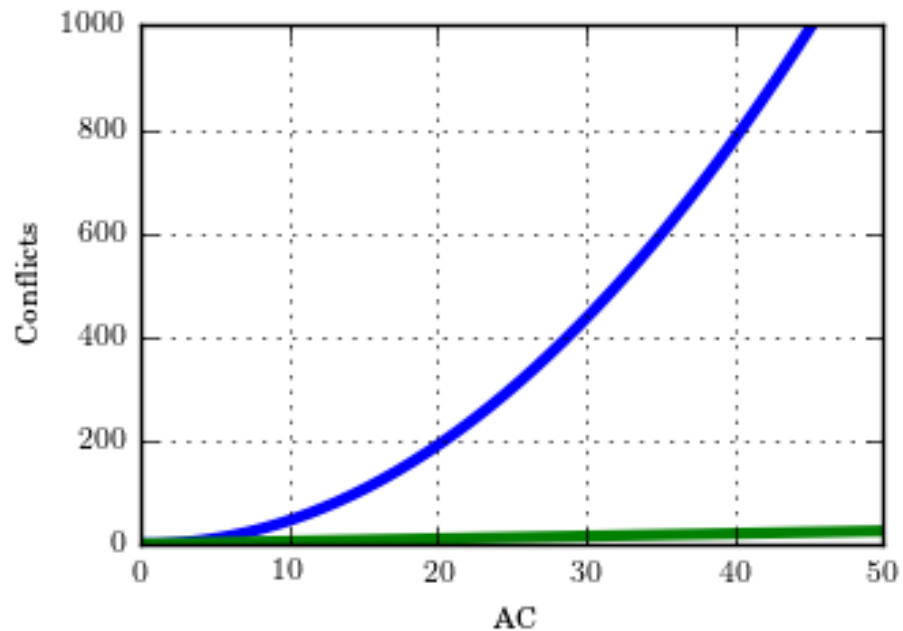
TCAS message duration: 56 μ s

Ref: Barhydt, 1999

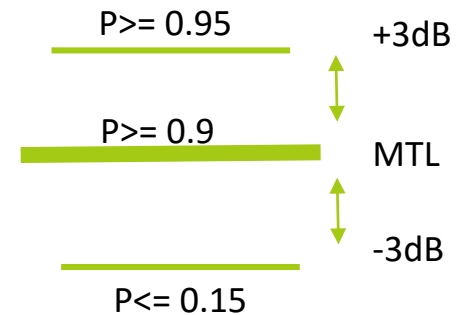
Centralized vs De-centralized

$$\frac{n \cdot (n-1)}{2}$$

$$\frac{(n-1)}{2}$$



Reception probability (range)



- Process: based on link budget

1. Free Space path Loss FSPL/NM

$$S_{rec} = S_{transmit} - FSPL_{NM} - 20 \times \log(r) = S_{transmit} - 98.55 - 20 \times \log(r) \quad (1)$$

2. Received power wrt distance

$$r = 10^{\frac{-(S_{rec} - FSPL_{NM})}{20}} = e^{-(S_{rec} - FSPL_{NM}) \left(\frac{\ln(10)}{20} \right)} \quad (2)$$

3. Reception probability wrt received power, based on MOPS/MTL, introduce k

$$p(S_{rec}) = 1 - e^{-k(S_{rec} - S_{rec0}) \left(\frac{\ln(10)}{20} \right)} = 1 - 10^{-k \frac{(S_{rec} - S_{rec0})}{20}}, S_{rec} \geq S_{rec0} \quad (3)$$

4. Convert to Reception prob wrt range (subs 1 in 3)

$$p(r) = 1 - \left(r \times e^{-(FSPL_{1NM} - S_{rec0}) \left(\frac{\ln(10)}{20} \right)} \right)^k = 1 - \left(r \times 10^{-\frac{(FSPL_{1NM} - S_{rec0})}{20}} \right)^k = 1 - \left(\frac{r}{r_0} \right)^k, r \geq r_0 \quad (4)$$

5. Obtain variables

$$1 - \left(\frac{r}{r_0} \right)^k, r \geq r_0$$