Department of Computer Science

UNIVERSITY OF OXFORD

OpenSky: A Swiss Army Knife for Air Traffic Security Research

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September 15, 2015

OPENSKY
NETWORK

http://www.opensky-network.org

- Original motivation: Security research into ADS-B
- Basic testing with single sensors in our lab
- Collaboration across countries and labs, sharing of data
- Development of the OpenSky idea: formalisation and development of adequate research and sharing infrastructure
- Registered association since 2014

Who and What is OpenSky?

- A large-scale ADS-B sensor network (online Jan. 2013)
- Cheap ADS-B sensors distributed (mostly) in Europe
- Receivers are connected over the Internet
- Access to raw ADS-B data and PHY-layer information

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
armasuisse

FH
Bern University
of Applied Sciences

CWI
Centrum Wiskunde & Informatica

disco
DISTRIBUTED COMPUTER SYSTEMS

EURECOM
Sophia Antipolis

USI/SUPSI
Istituto
Dalle Molle
di studi
sull'intelligenza
artificiale
IDSIA

institute
iMdea
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SeRo
Systems

Transkom
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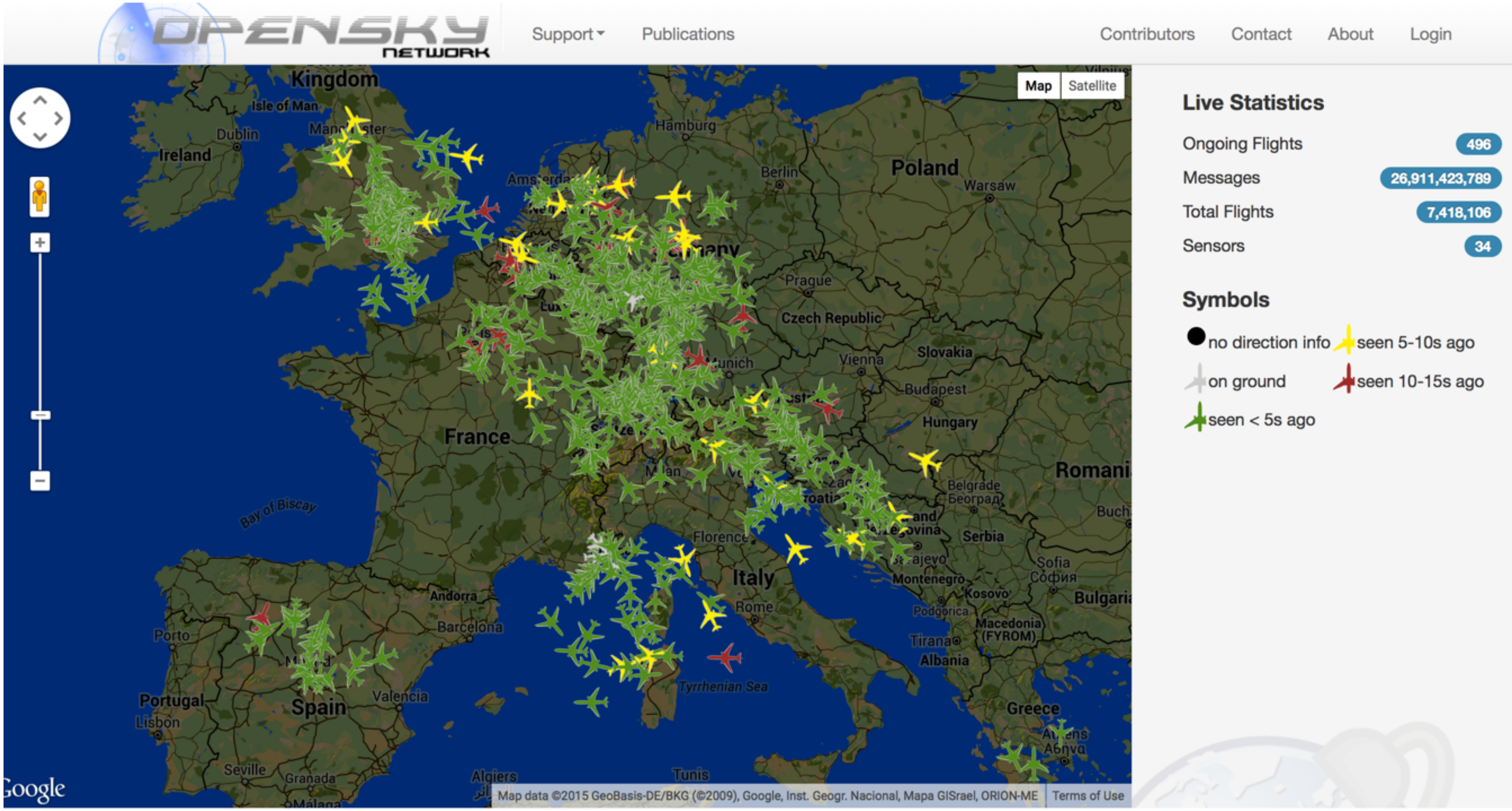
OpenSky Basis

Various off-the-shelf sensors installed by motivated volunteers.

OpenSky Frontend



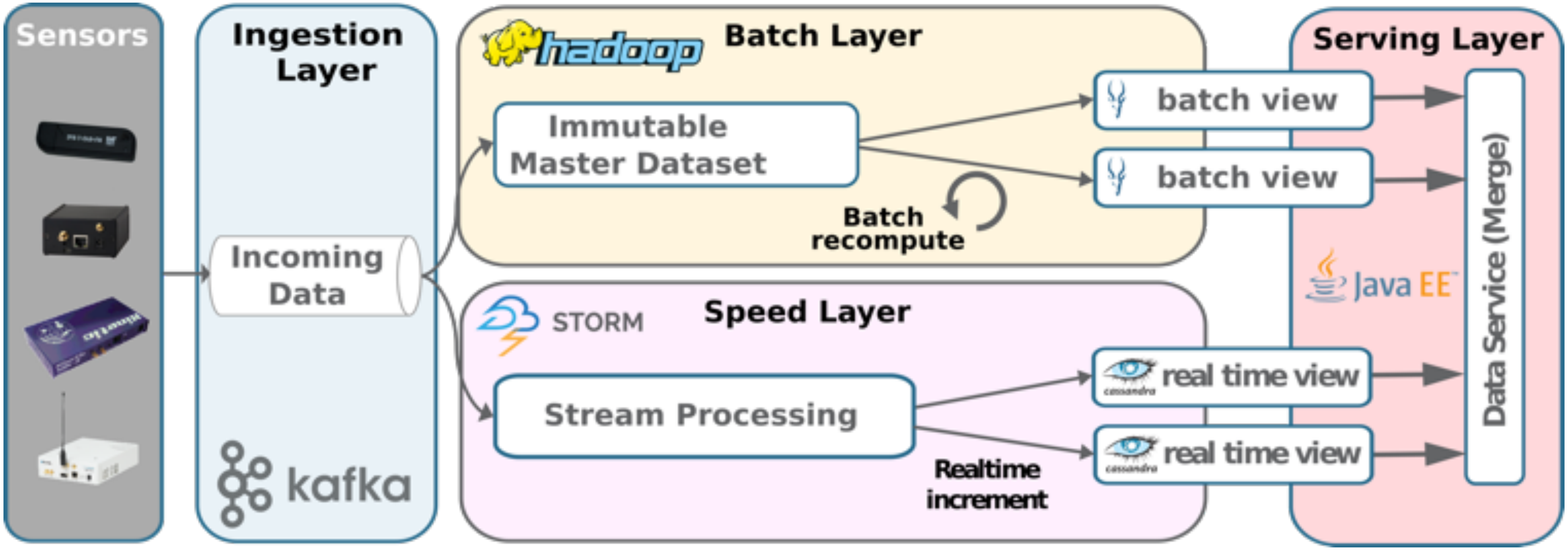
Live Statistics

Ongoing Flights	496
Messages	26,911,423,789
Total Flights	7,418,106
Sensors	34

Symbols

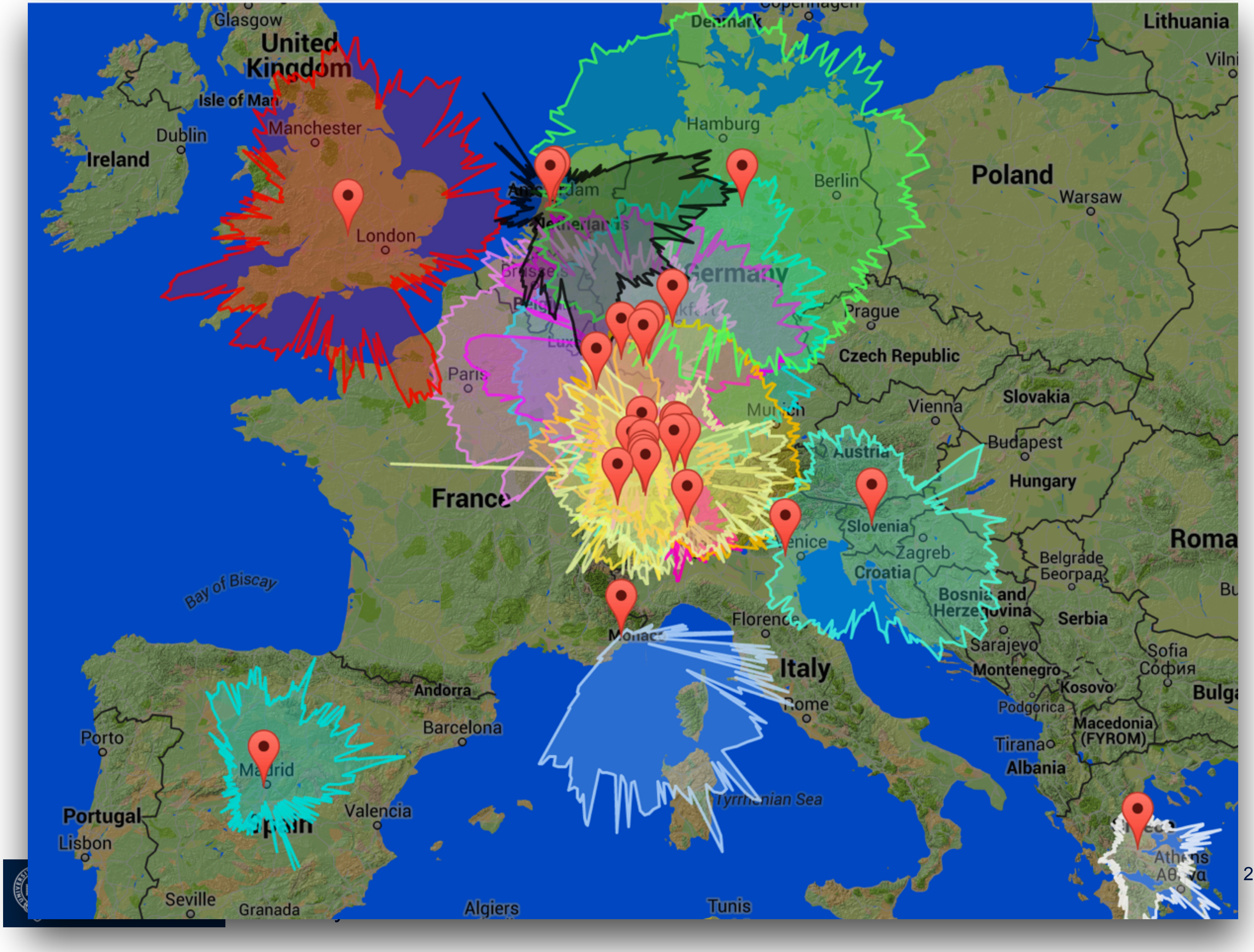
● no direction info	✈ seen 5-10s ago
✈ on ground	✈ seen 10-15s ago
✈ seen < 5s ago	

OpenSky Backend



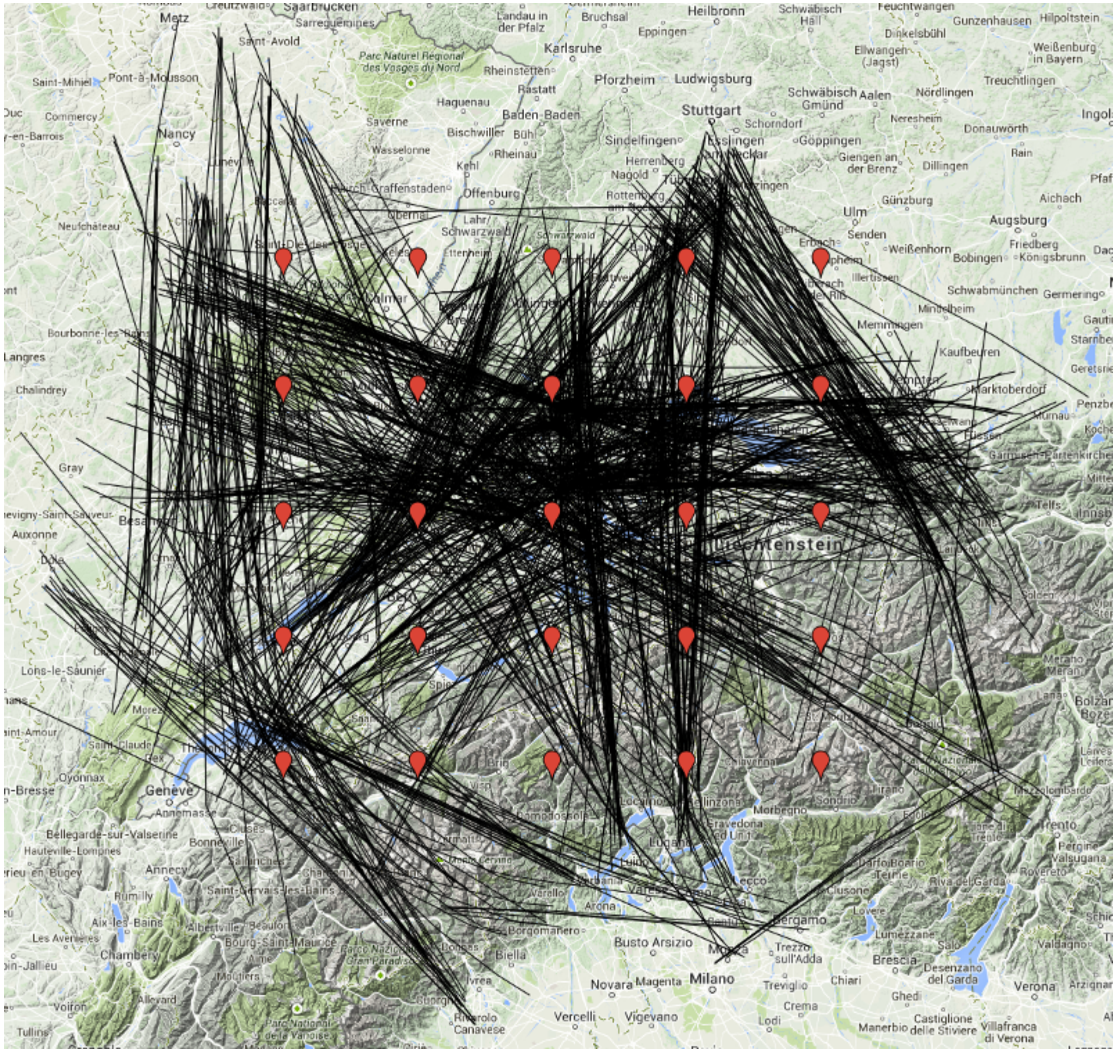
- Move from RDMS architecture to big data system
- Four horizontally scalable layers
- Enables real-time processing of all received messages in <20ms, and fast large-scale analysis over all data

Current OpenSky Coverage



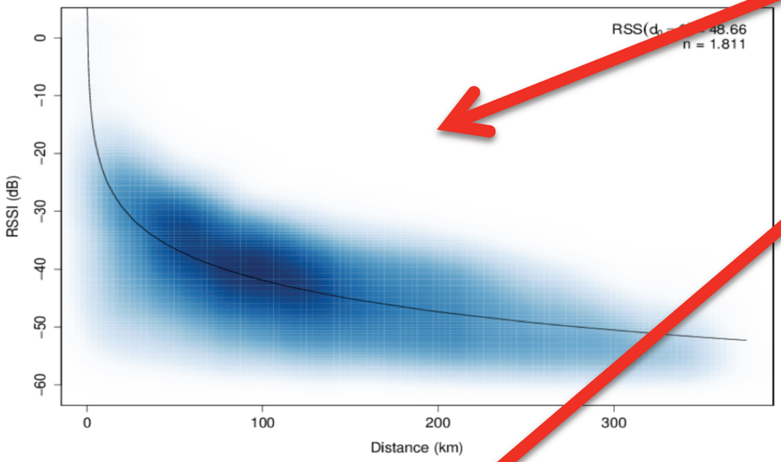
Example of an OpenSky Dataset

- Contents
  - ID
  - Velocity
  - Position
  - …
- Meta Data
  - Physical layer data
    - RSS
    - Loss
    - SNR
  - Timestamps
  - Sensor ID



ADS-B Channel Analysis with OpenSky

Propagation Model



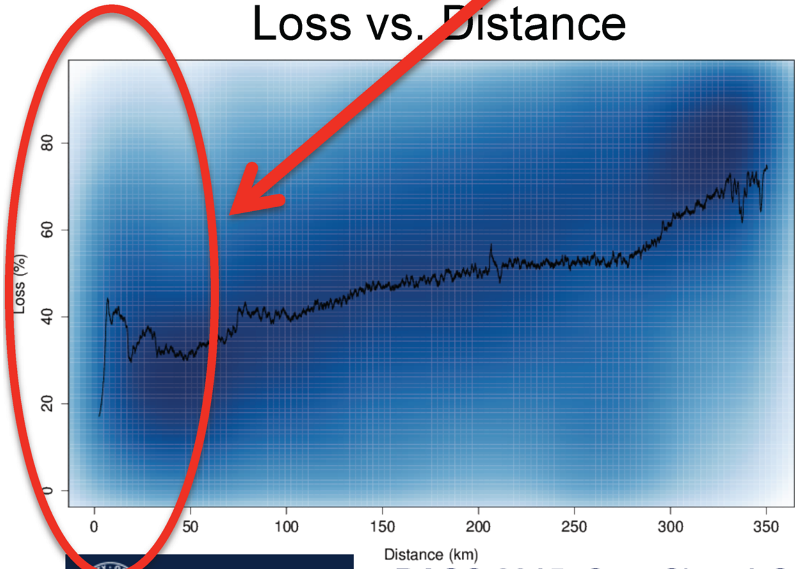
Log-distance Path Loss Model (LDPL)

Doughnut effect: noticeable drop in reception quality of messages sent in close proximity to a receiver.

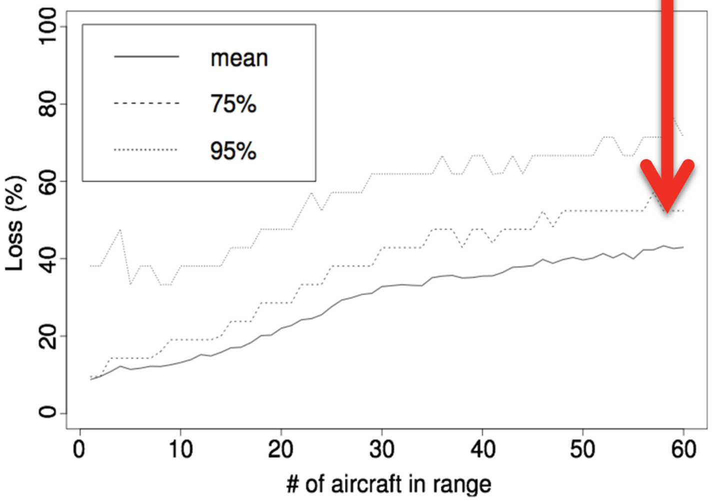
1090 MHz channel utilization is very high

60 aircraft → 40% message loss

Loss vs. Distance



Loss vs. Traffic

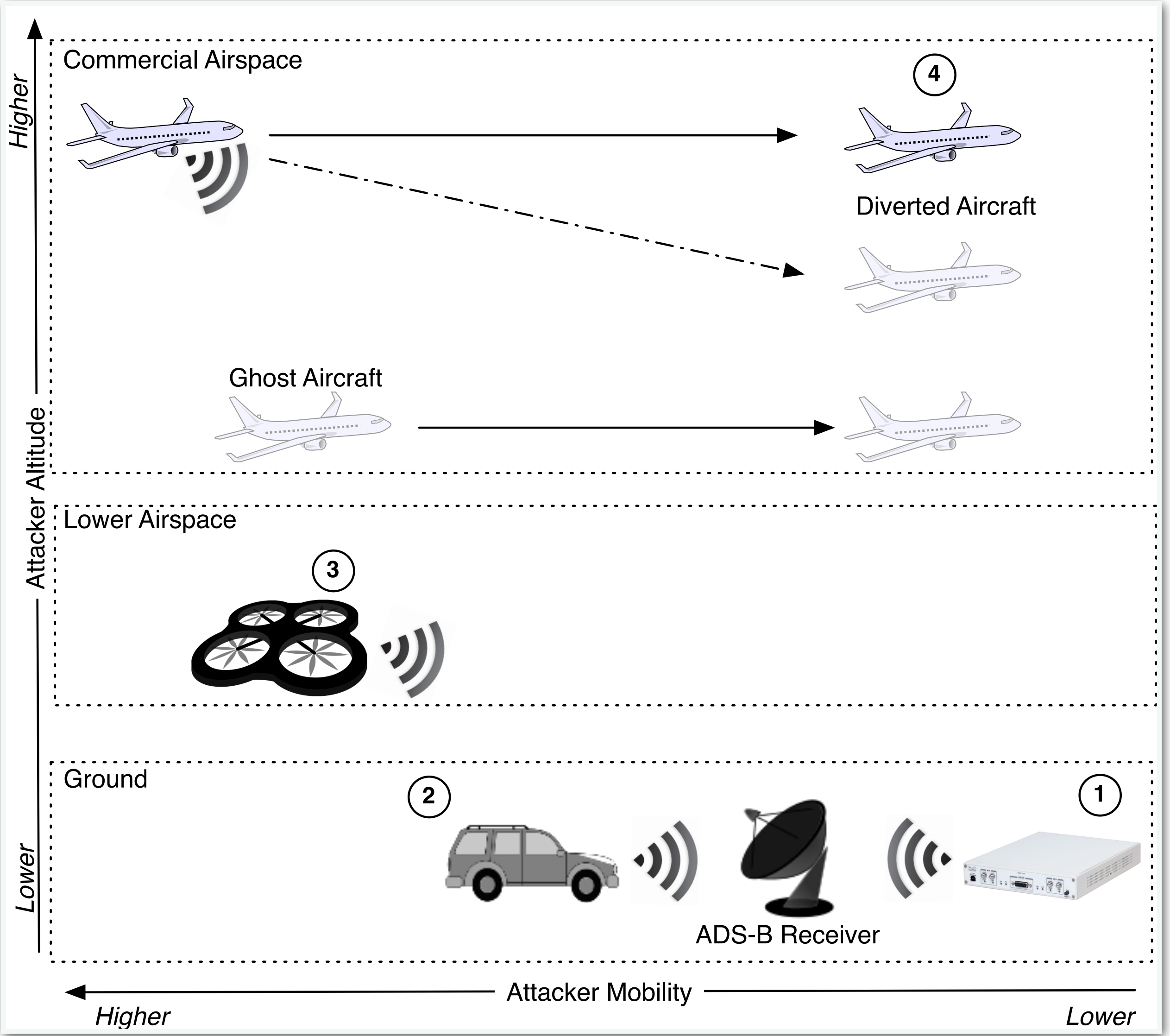


Exemplary Security Research with OpenSky

- Aircraft Location Verification
- Secure Track Verification
- Physical Layer Intrusion Detection
- Transponder Fingerprinting
- Event Detection

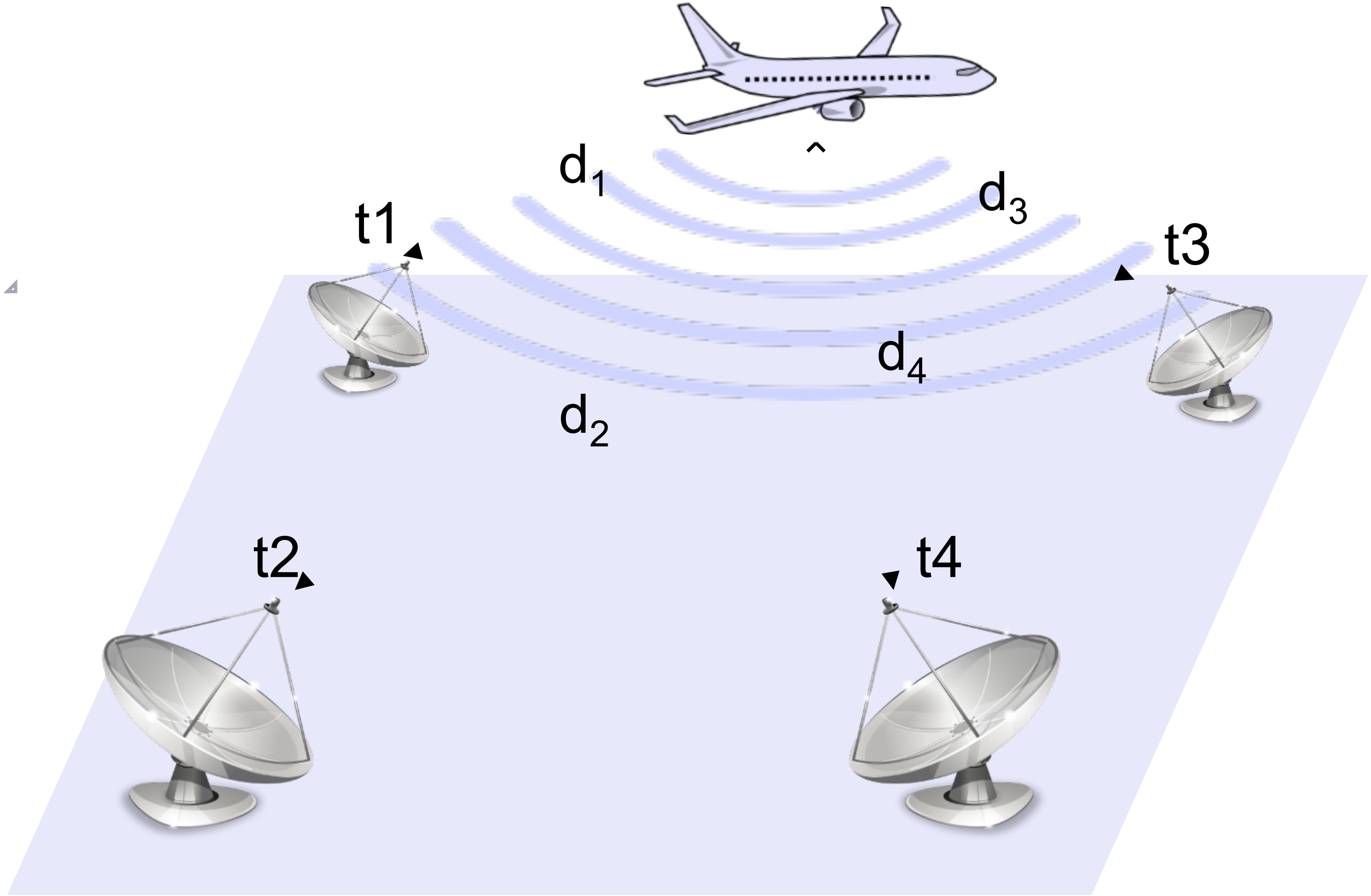
- **For all the details, read the papers on the OpenSky website!**

Some Attacker Models

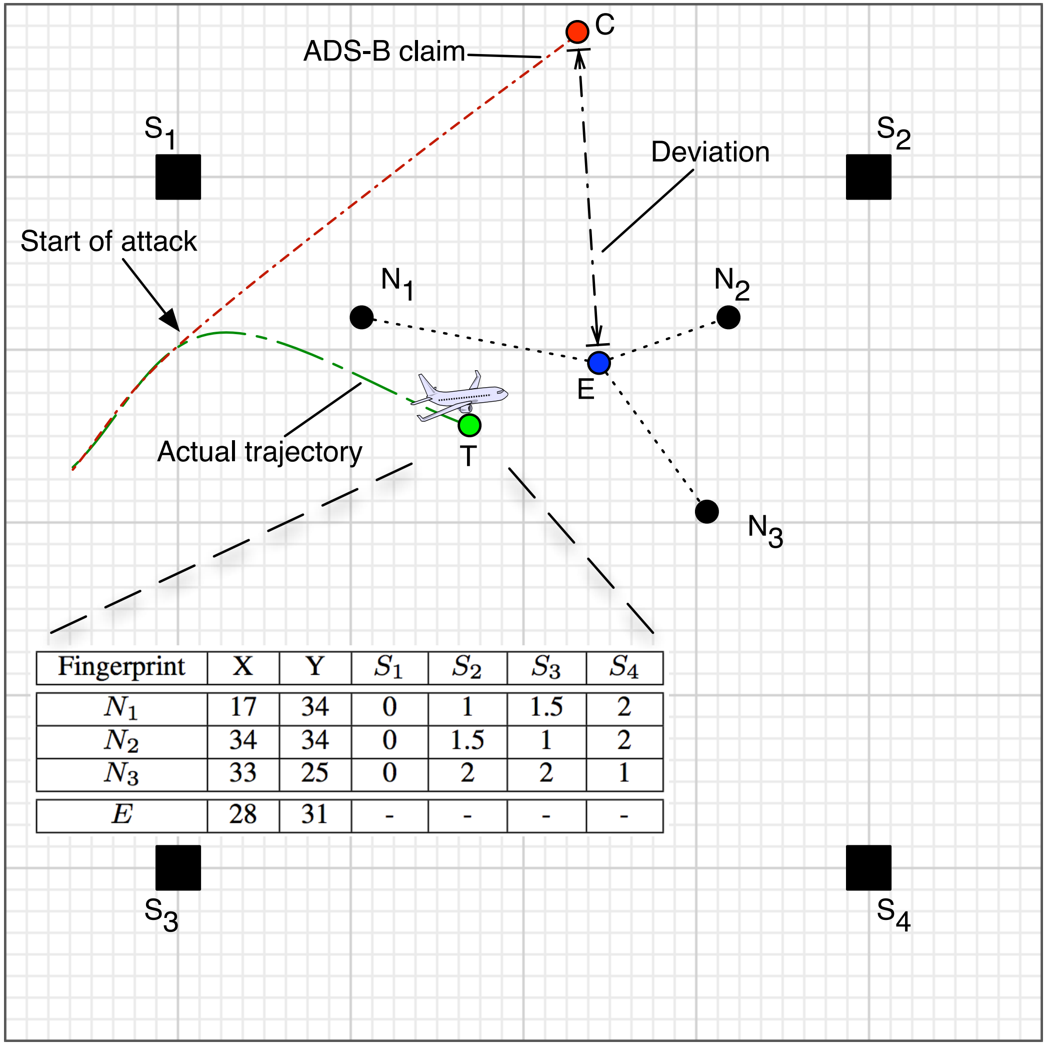


Aircraft Location Verification

Aircraft Location Verification: Multilateration



Aircraft Location V



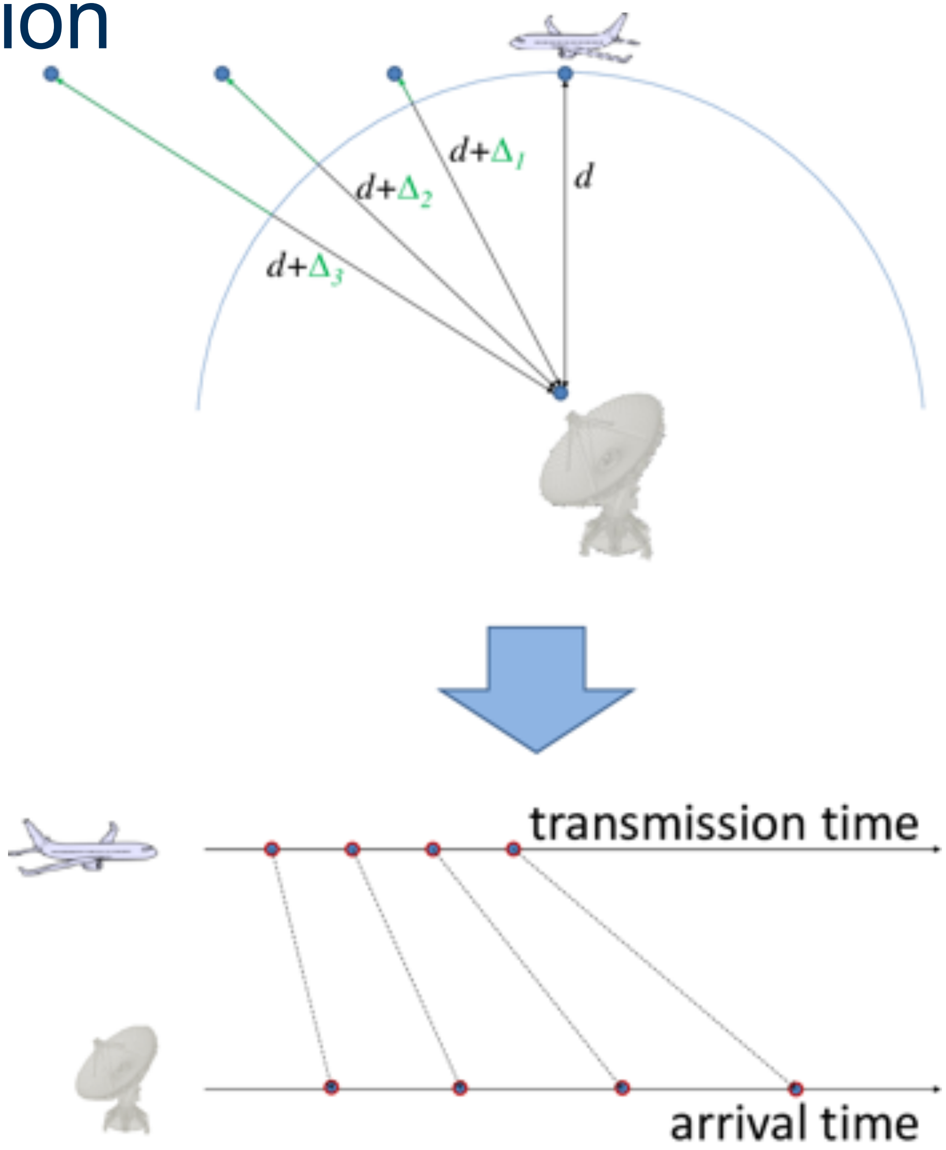
Fingerprint	X	Y	S_1	S_2	S_3	S_4
N_1	17	34	0	1	1.5	2
N_2	34	34	0	1.5	1	2
N_3	33	25	0	2	2	1
E	28	31	-	-	-	-

[1] “Lightweight Location Verification in Air Traffic Surveillance Networks.” Martin Strohmeier, Vincent Lenders and Ivan Martinovic. In Proceedings of the 1st ACM Workshop on Cyber−Physical System Security (CPSS '15). April, 2015.

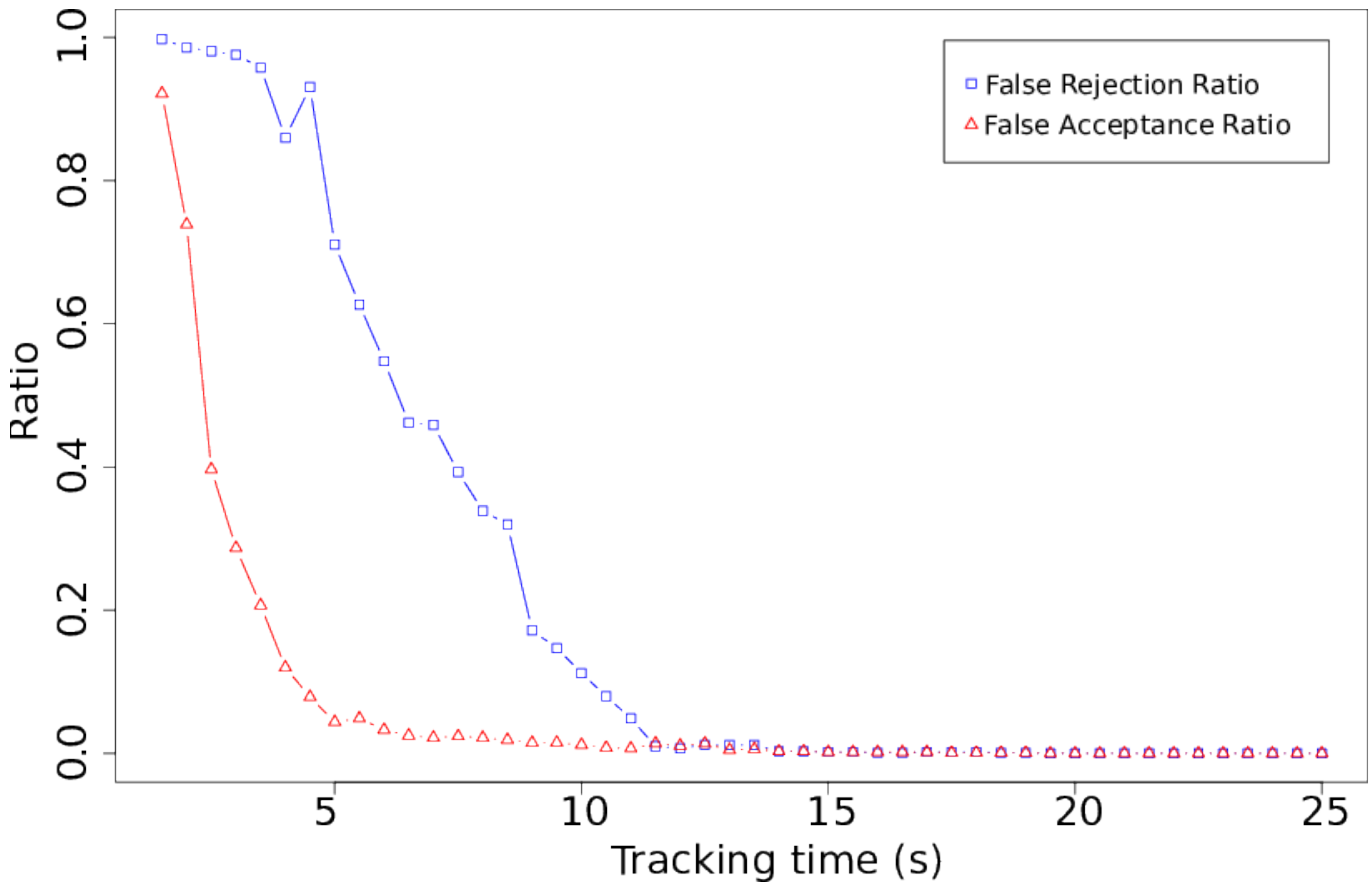
Secure Track Verification

Secure Track Verification

- New approach, exploiting the inherent mobility of aircraft
- Use sequences of location claims, measure differences in propagation delay to receivers
- Detect any deviation
- Not dependent on tight synchronisation and hardware



Secure Track Verification

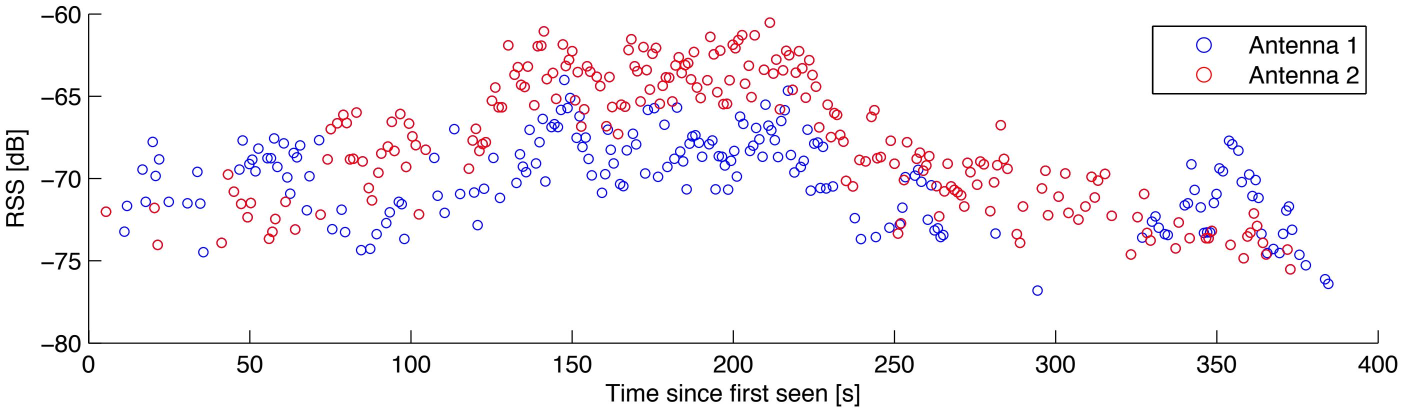


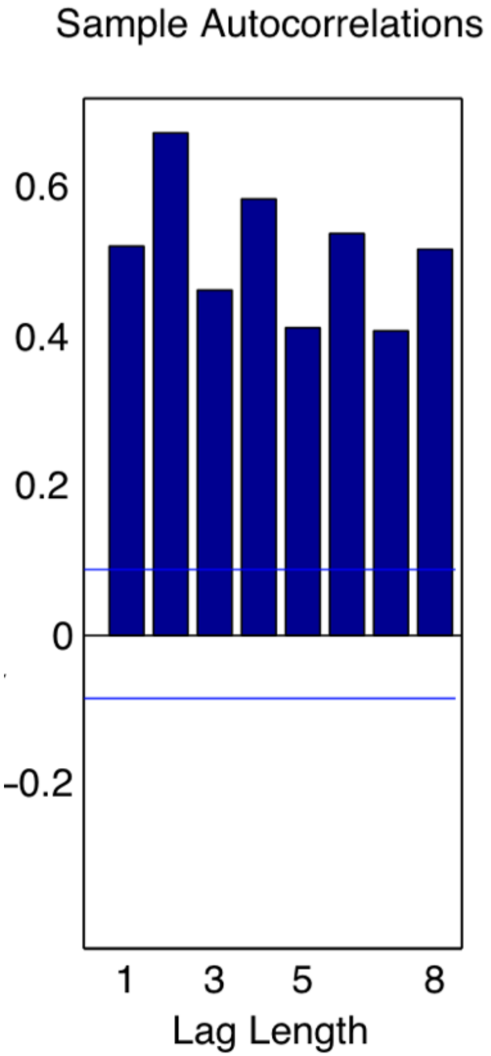
[2] “Secure Track Verification.” Matthias Schäfer, Vincent Lenders and Jens B Schmitt. In IEEE Symposium on Security and Privacy (S&P) May 2015.

PHY-Layer Intrusion Detection

PHY-Layer Features

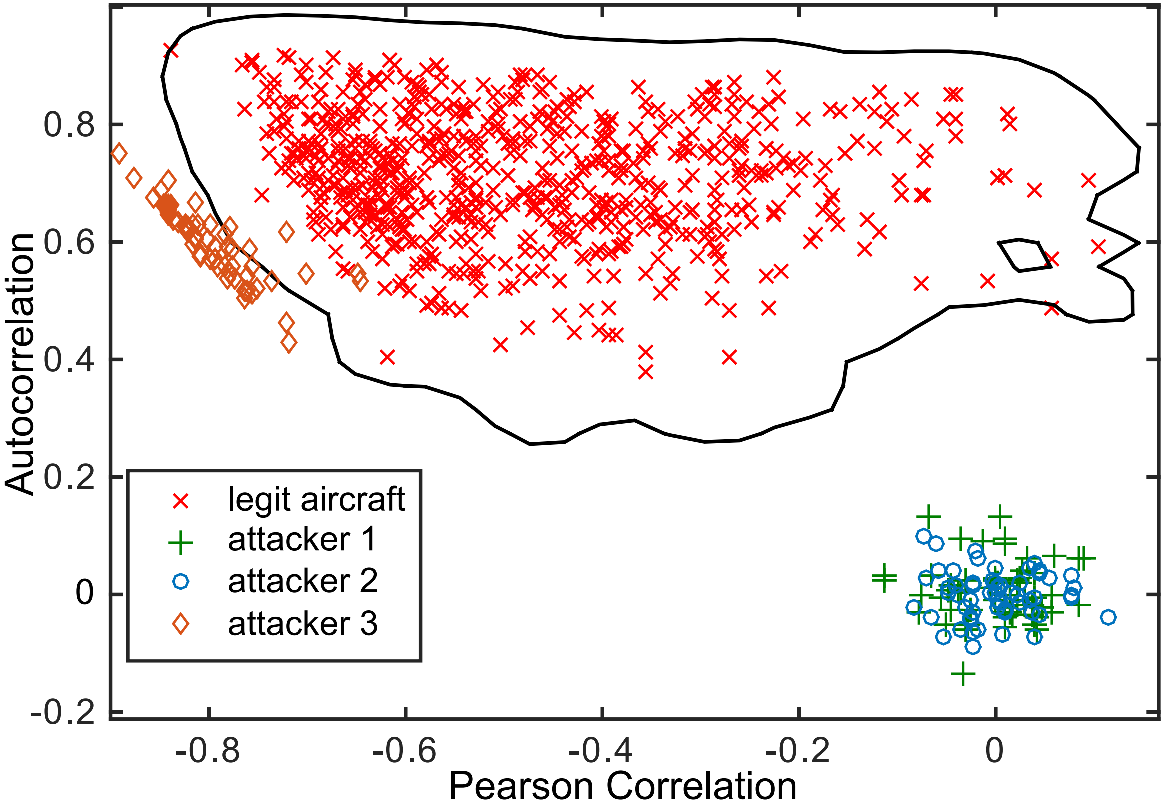
- Commercial ADS-B transponders use two antennas
- Possible to detect single-antenna attackers with high certainty by exploiting distinct autocorrelation features





Anomaly Detection

- One-class classification
- Simulation of different attacker types
  - constant sending strength
  - random sending strength
  - adaptive sending strength

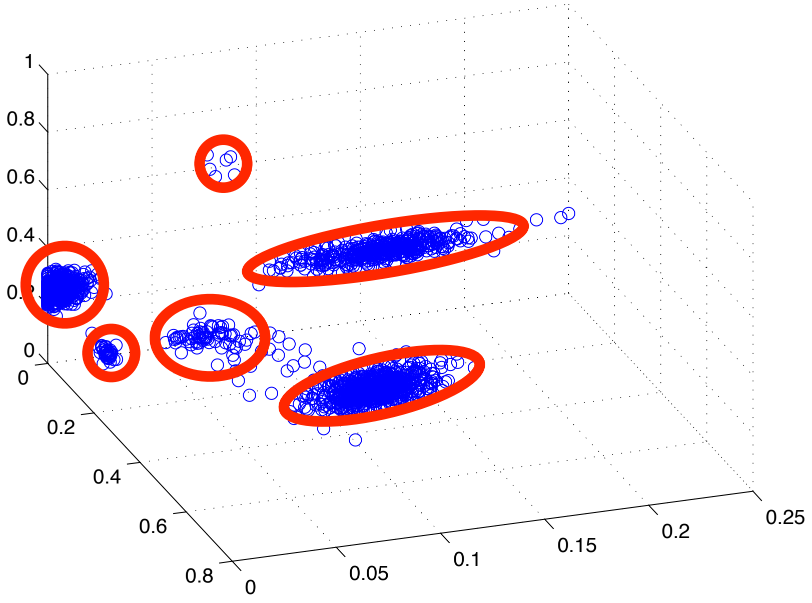


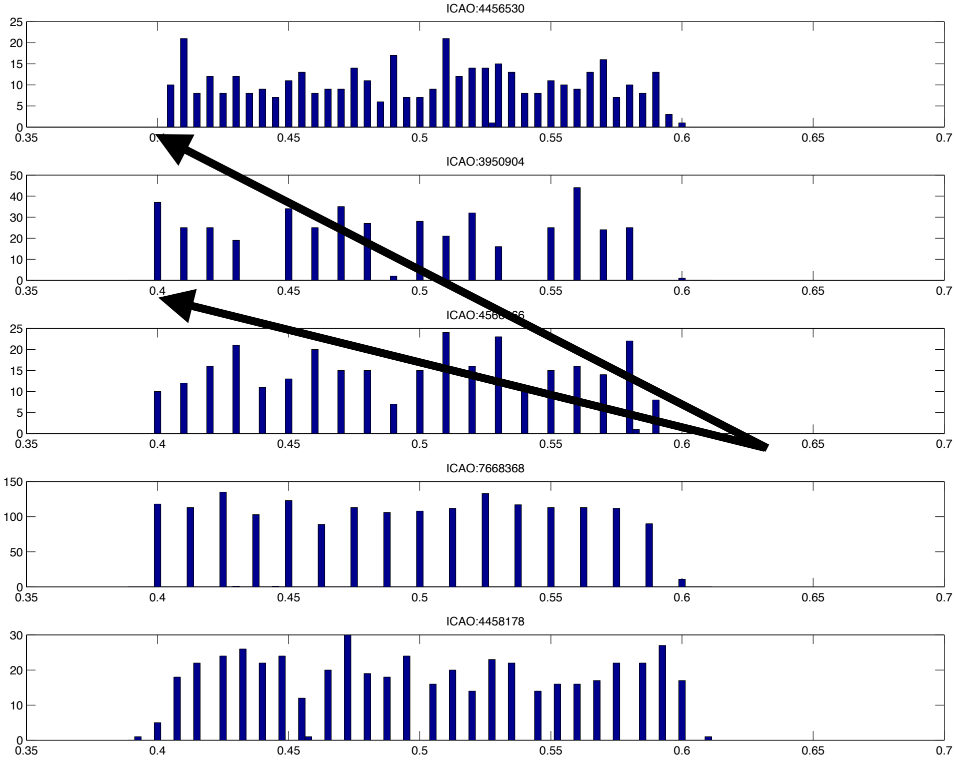
[3] “Intrusion Detection for Airborne Communication using PHY−Layer Information.” Martin Strohmeier, Vincent Lenders and Ivan Martinovic. In Detection of Intrusions and Malware, and Vulnerability Assessment (DIMVA). July, 2015.

Transponder Fingerprinting

Transponder Fingerprinting

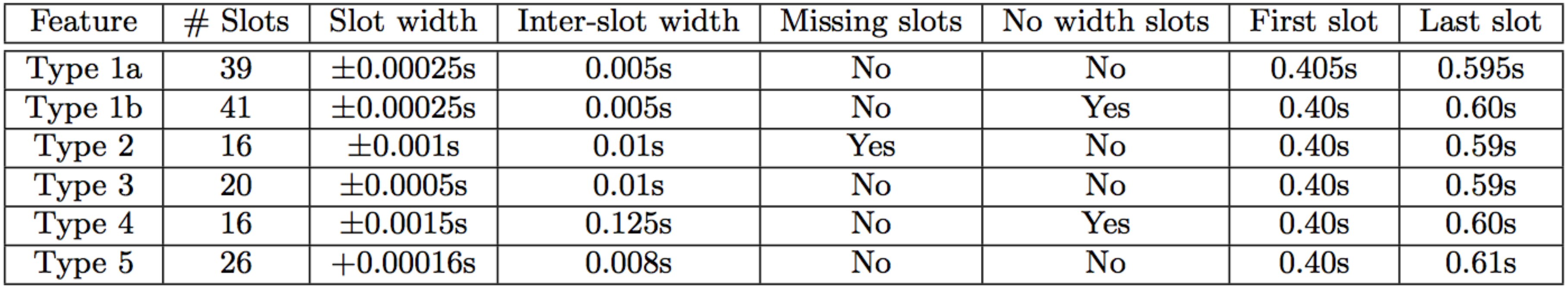
- Different ADS-B transponder types / implementations used in the commercial aviation market.
- Several features based on random message inter-arrival times.





Transponder Fingerprinting

- **6 main types.** With 100 samples, prediction accuracy of 99.91%
- Some special cases with unique feature combinations, making aircraft potentially identifiable, even when using pseudonyms / not broadcasting their ID.



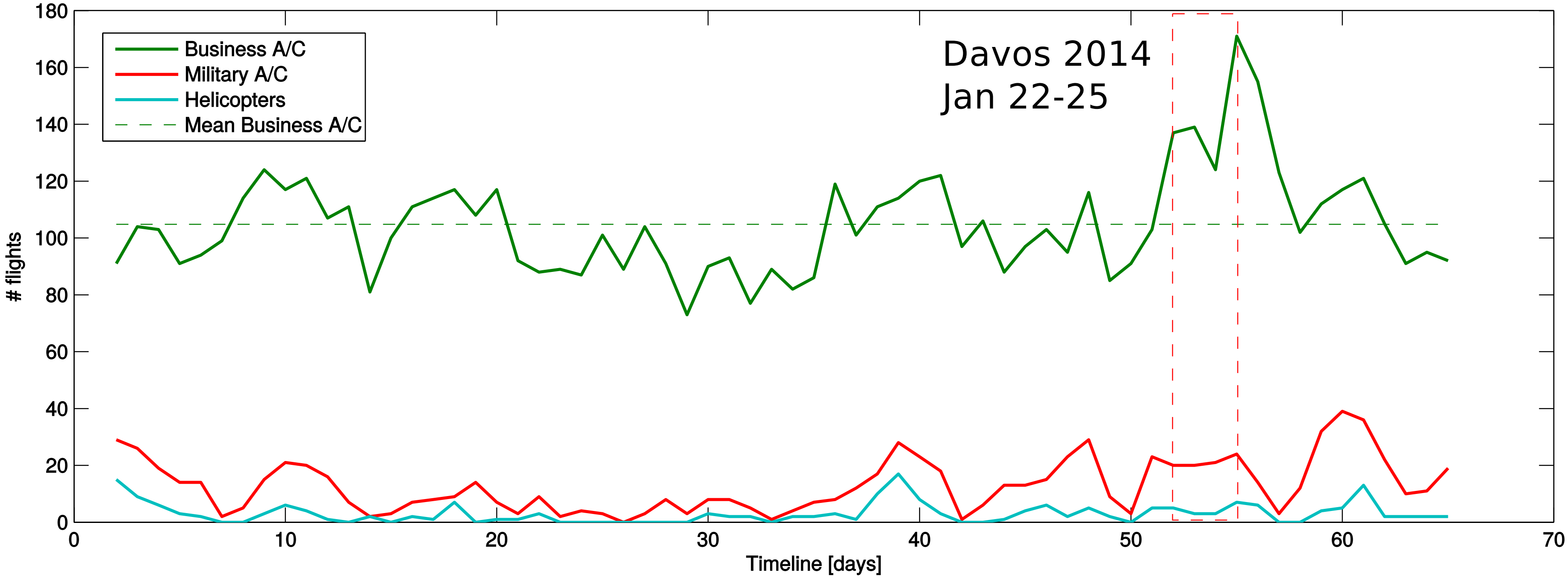
Feature	# Slots	Slot width	Inter-slot width	Missing slots	No width slots	First slot	Last slot
Type 1a	39	±0.00025s	0.005s	No	No	0.405s	0.595s
Type 1b	41	±0.00025s	0.005s	No	Yes	0.40s	0.60s
Type 2	16	±0.001s	0.01s	Yes	No	0.40s	0.59s
Type 3	20	±0.0005s	0.01s	No	No	0.40s	0.59s
Type 4	16	±0.0015s	0.125s	No	Yes	0.40s	0.60s
Type 5	26	+0.00016s	0.008s	No	No	0.40s	0.61s

[4] “On Passive Data Link Layer Fingerprinting of Aircraft Transponders.” Martin Strohmeier and Ivan Martinovic. In 1st ACM Workshop on Cyber−Physical Systems Security & Privacy (CPS−SPC). October, 2015.

Event Detection

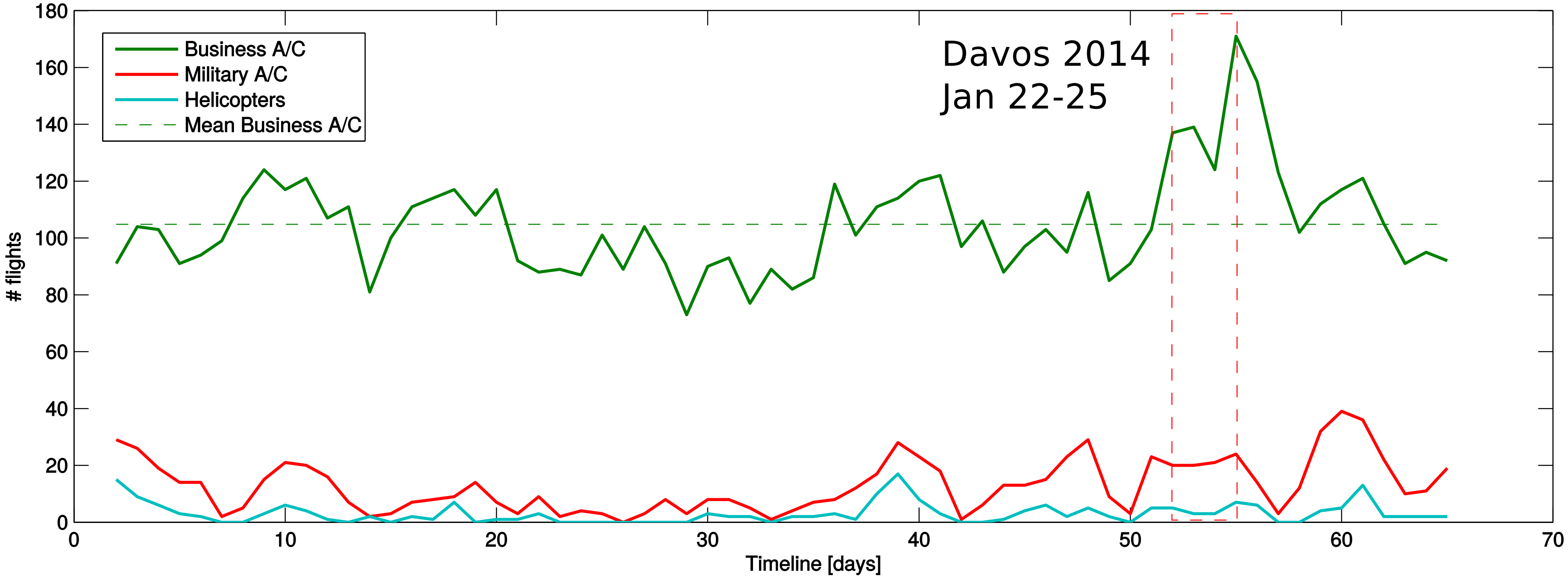
Event Detection

- Time series analysis to identify anomalies.
- Combine OpenSky ADS-B sensor data with publicly available databases about 24-bit ICAO identifiers, aircraft types and airline to track various types of activity.
- Data from 2 OpenSky sensors closest to Davos / Zurich:



Event Detection

- >70% increase from mean and 45% increase over previous peaks.
- Pitfalls:
  - Data quality / consistency.
  - Need to take long-term trends into account / compare to recent data.
  - Doesn't tell us *what* is going on!



Conclusion

- OpenSky provides a scalable, open, and collaborative architecture for air traffic research.
- Communications security is an important problem in modern aviation.
- Our research using OpenSky proposes and analyses attack detection using several different approaches.
- Security and privacy has been OpenSky's main theme but the data is used for many other applications now.
- Check out http://opensky-network.org if you are interested further in air traffic communication research, security and non-security related.

References

[1] “Lightweight Location Verification in Air Traffic Surveillance Networks”, Martin Strohmeier, Vincent Lenders and Ivan Martinovic In Proceedings of the 1st ACM Workshop on Cyber−Physical System Security (CPSS '15). April, 2015.

[2] “Secure Track Verification”, Matthias Schäfer, Vincent Lenders and Jens B Schmitt. In IEEE Symposium on Security and Privacy (S&P). May 2015.

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Questions?