

Mode S Surveillance Principle

Surveillance/MICA Workshop

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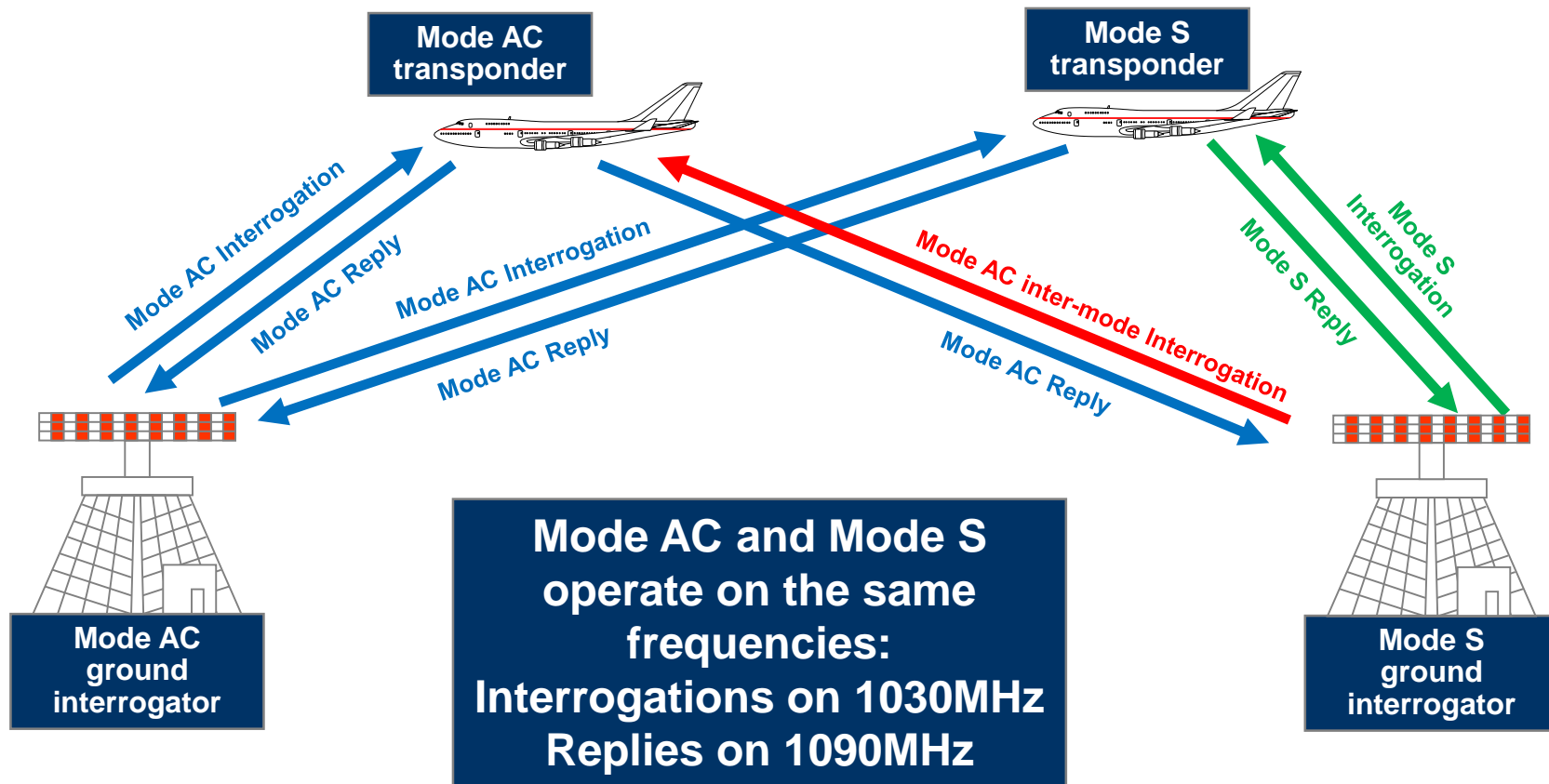
Objective

- Description of the key technical principles of Mode S radar
 - Lockout,
 - Interrogator Code (IC)
 - more details in “Operation on II and SI Code, II/SI Code Operation”
 - Coverage Maps
 - more details in “Mode S Radar Coverage”
 - Clusters
- Description of Mode S radar operation, interrogations and replies
- Overview of other surveillance systems:
 - ADS-B
 - Multilateration (WAM)
 - Airborne Collision Avoidance System (ACAS)

■ S = Selective

- Selectively communicate with **individual** aircraft
 - Unique Mode S address for each aircraft (24-bit address)
 - Allocated by the State at registration
 - An 'address' for Mode S radar (IC = Interrogator Code)
 - Provided by the EUROCONTROL MICA (Mode S Interrogator Code Allocation) Cell
 - Backward compatible with old systems (Mode AC)

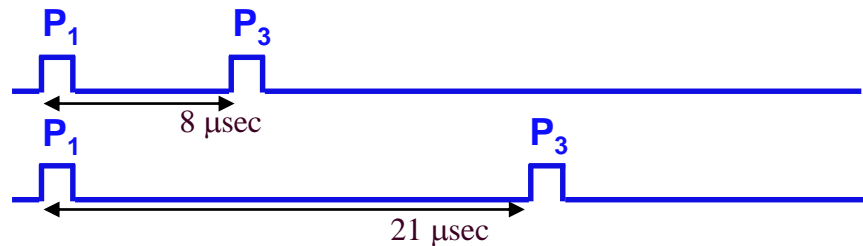
Mode S and Mode AC Interrogations and Replies



Mode S and Mode AC interoperability

Uplink Pulse Formats (1030 MHz)

MODE AC

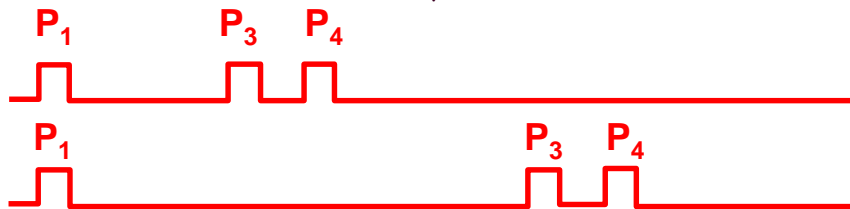


Name

MODE A

MODE C

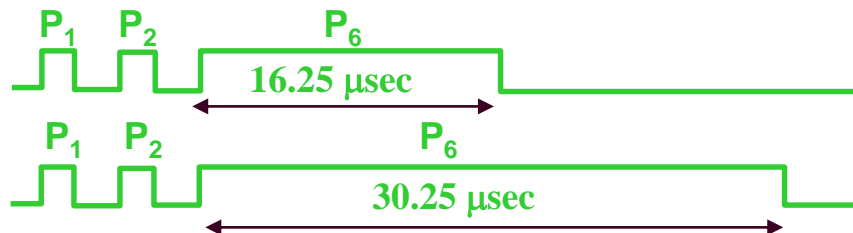
INTERMODE



MODE A
ALL-CALL

MODE C
ALL-CALL

MODE S



MODE S Short

MODE S Long

Interrogation Pulse Sequences

	Mode-AC transponder	Mode-S transponder
MODE A	MODE A	MODE A
MODE C	MODE C	MODE C
MODE A ALL-CALL	MODE A	No Reply
MODE C ALL-CALL	MODE C	No Reply
MODE S Short	No Reply	MODE S if addressed or All-Call
MODE S Long	No Reply	MODE S if addressed or All-Call

Transponder Replies (1090 MHz)

Mode S radar interrogations

1. ACQUISITION

A Mode S radar sends All-Call interrogations to detect and acquire incoming aircraft:

- Broadcast interrogations → addressed to all aircraft
- Aircraft reply with its 24bit Mode S address

2. SELECTIVE INTERROGATIONS

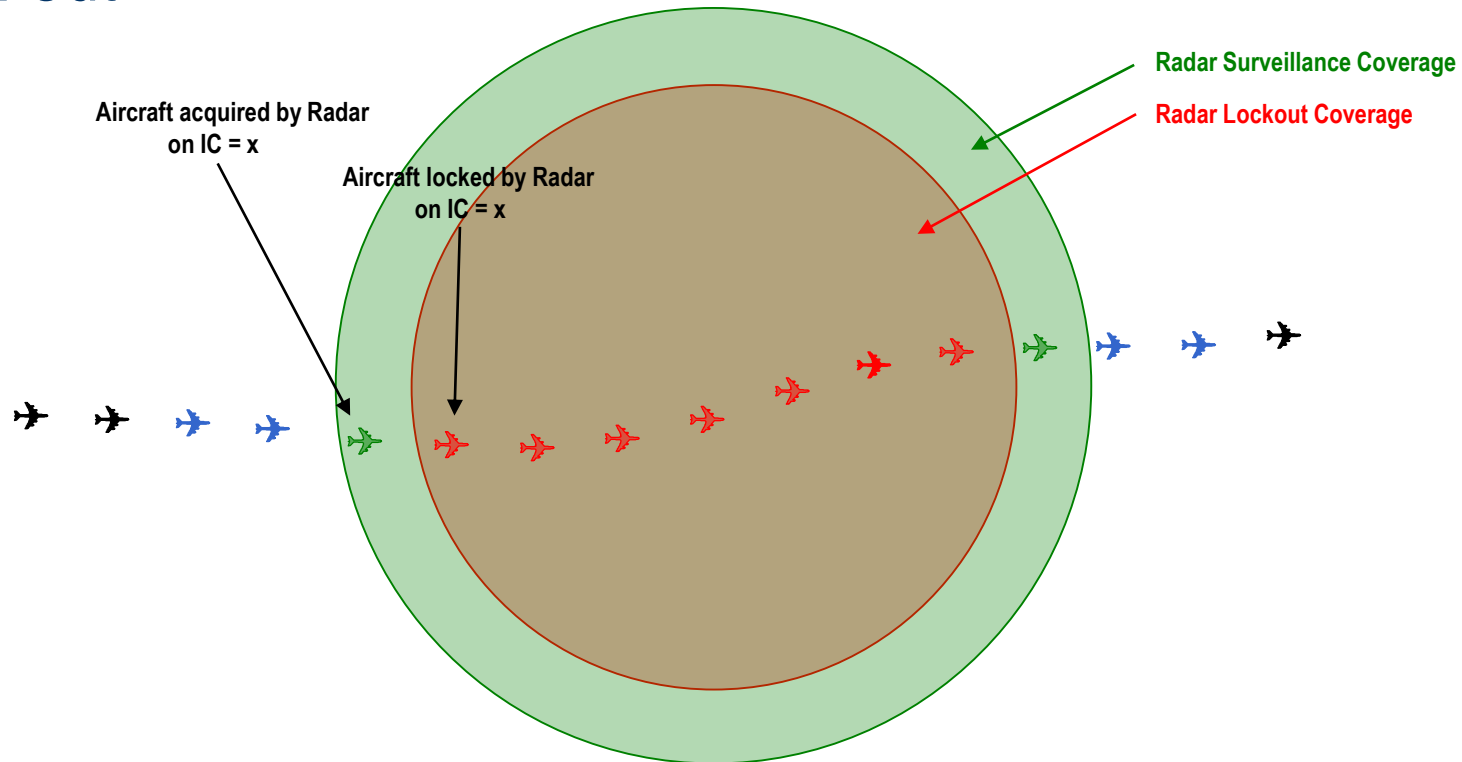
Once acquired, the Mode S radar sends selective interrogations to the aircraft using the 24bit Mode S address received during the acquisition

3. LOCKOUT

Once acquired, the Mode S radar locks the aircraft to prevent it to reply to All-Call interrogations (lockout request in selective interrogations)

- All-Call replies are useless once the radar has acquired the aircraft.

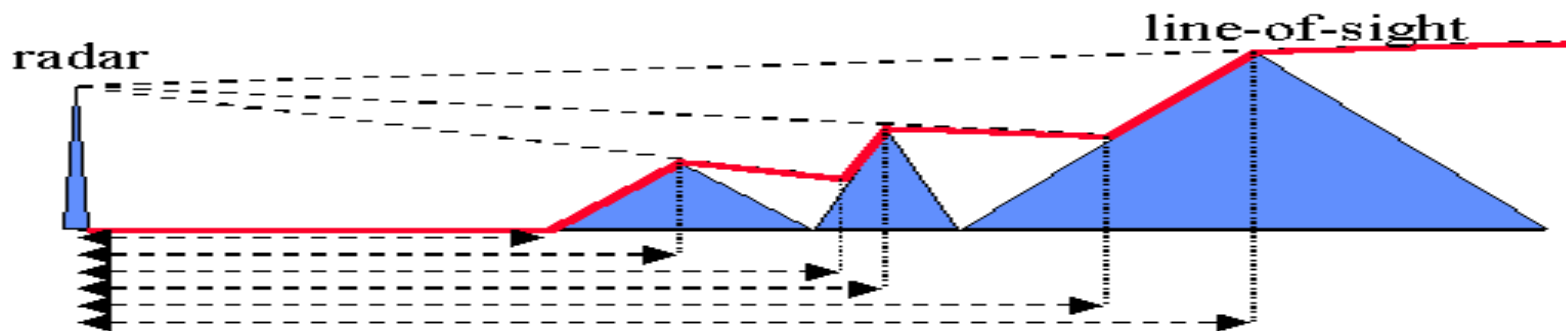
Aircraft acquisition, selective interrogations and lock-out



- ✈ Aircraft not in line of sight of radar or not in power budget → does not receive All-Call interrogations (broadcast)
- ✈ Aircraft outside surveillance coverage → receives All-Call interrogations (broadcast) and replies, but replies not processed by radar
- ✈ Aircraft acquired by radar in surveillance coverage → selective interrogations (Roll-Call)
→ not locked: receive All-Call interrogations and replies
- ✈ Aircraft locked by radar in lockout coverage → does not reply to All-Call interrogations

Line of Sight

- SSR coverage is limited by **Line of Sight**
 - Cone of Silence (or 'Overhead Gap')
 - Min & Max Elevations (e.g. 0 to 60 degrees)
 - Depends on antenna design and configuration
 - Obstacles



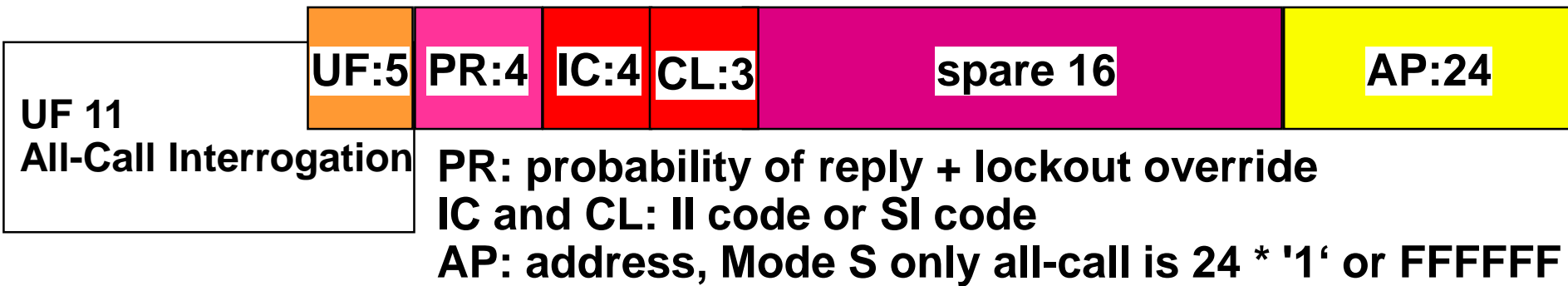
Aircraft Acquisition using All-Call

1. Mode S radar sends All-Call interrogations (UF11) to all aircraft (broadcast).
 - UF11 contains the IC (II or SI code) allocated to the Mode S radar
2. Mode S aircraft receives the All-Call interrogation and decodes the IC.
 - If it is not locked on this IC, the aircraft replies to the All-Call interrogation (All-Call reply – DF11).
 - The IC of the Mode S radar and the 24bits Mode S address of the aircraft are contained in the All-Call replies.
3. Mode S radar receives All-Call replies containing its own allocated IC
 - Decodes the 24bits Mode S address of the aircraft
 - Computes the aircraft position (range, azimuth)

➔ The aircraft is acquired

All-Call Format

Mode S Only All-Call Interrogation (UF 11) – 56 bits



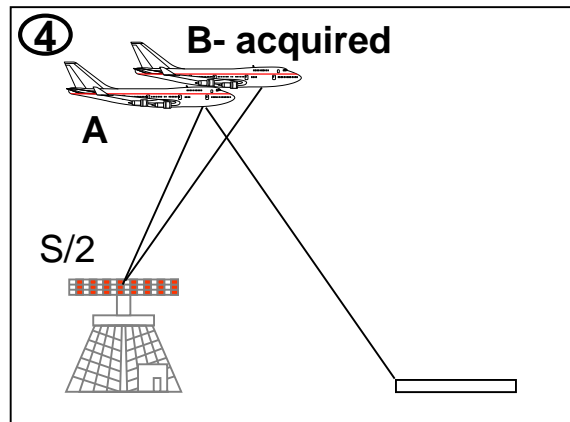
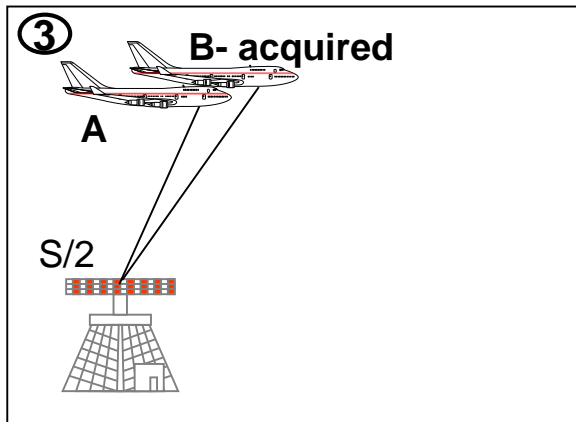
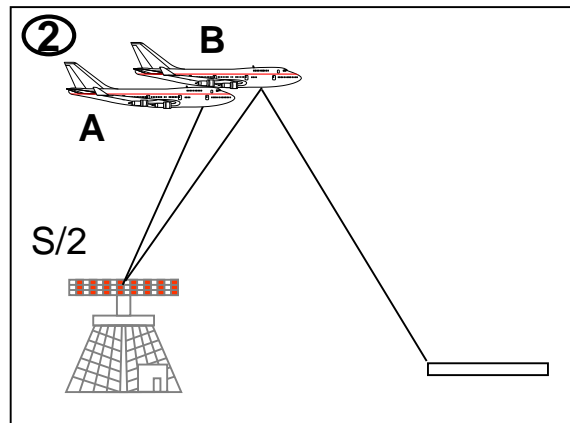
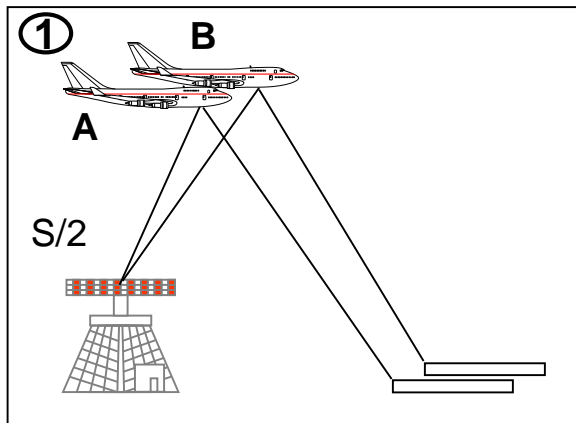
Mode S Only All-Call Reply (DF 11) – Short: 56 bits



Stochastic Acquisition and Lockout Override

- Stochastic Acquisition
 - Used for acquiring targets close in range
 - Probability of reply in All-Call interrogation
- Lockout Override
 - Disregard aircraft lockout on IC in All-Call interrogation
 - Can be stochastic
 - Can be applied by sector
 - Sectorised lockout override by azimuth sector
 - Should not be used except for fall-back (e.g. in case of IC conflict)

Stochastic Acquisition



Stochastic S/2 Interrogations with 50% set as PR

- ① A and B both reply
Replies overlap in time
Both are garbled and lost
- ② A decides No Reply (50%)
B replies
B acquired and locked out
- ③ B is locked out
A decides No Reply (50%)
- ④ B is locked out
A replies
A acquired and locked out

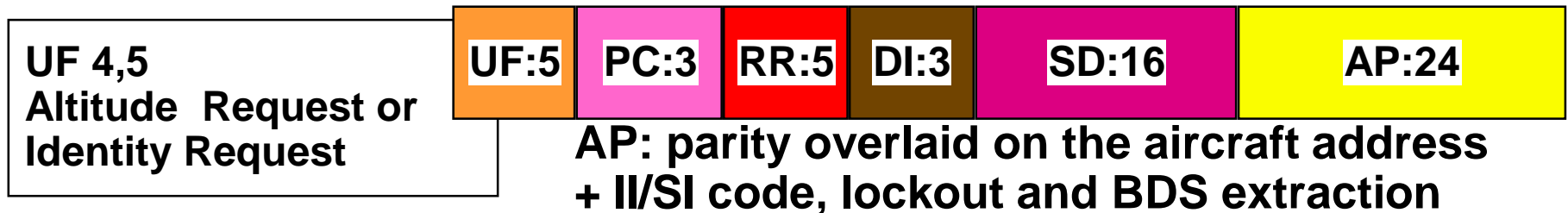
Selective Interrogations and Lockout

- Once an Mode S aircraft is acquired, the Mode S radar knows:
 - 24bit Mode S address of the aircraft
 - Position of the aircraft (range/azimuth)

- ➔ The Mode S radar sends selective interrogations to the aircraft using the 24bit Mode S address:
 - Only the aircraft having the correct 24bit Mode S address replies
 - Request Mode A Code or Altitude (Mode C)
 - Lockout request to prevent the aircraft to reply to All-Call interrogations from the same radar (on the IC of the radar)
 - All-Call replies are useless once the radar has acquired the aircraft.
 - May request the transfer of aircraft registers
 - BDS (Comm-B Data Selector)

Selective Interrogation and Reply Format

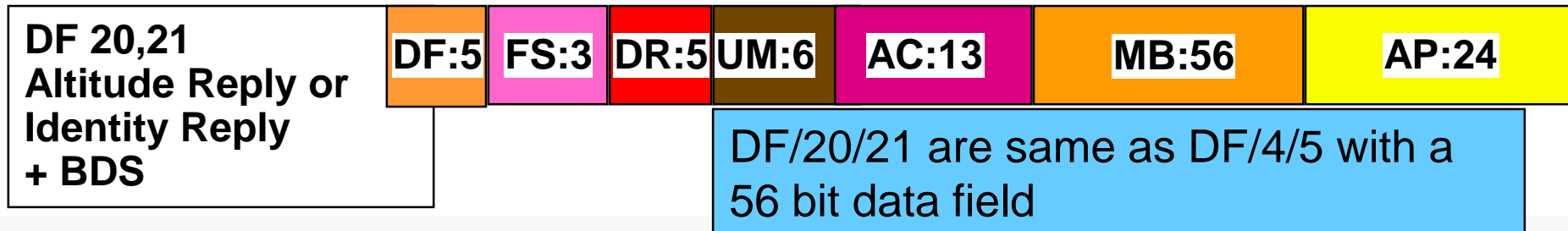
Surveillance Interrogation (UF 4 or 5) - 56 bits



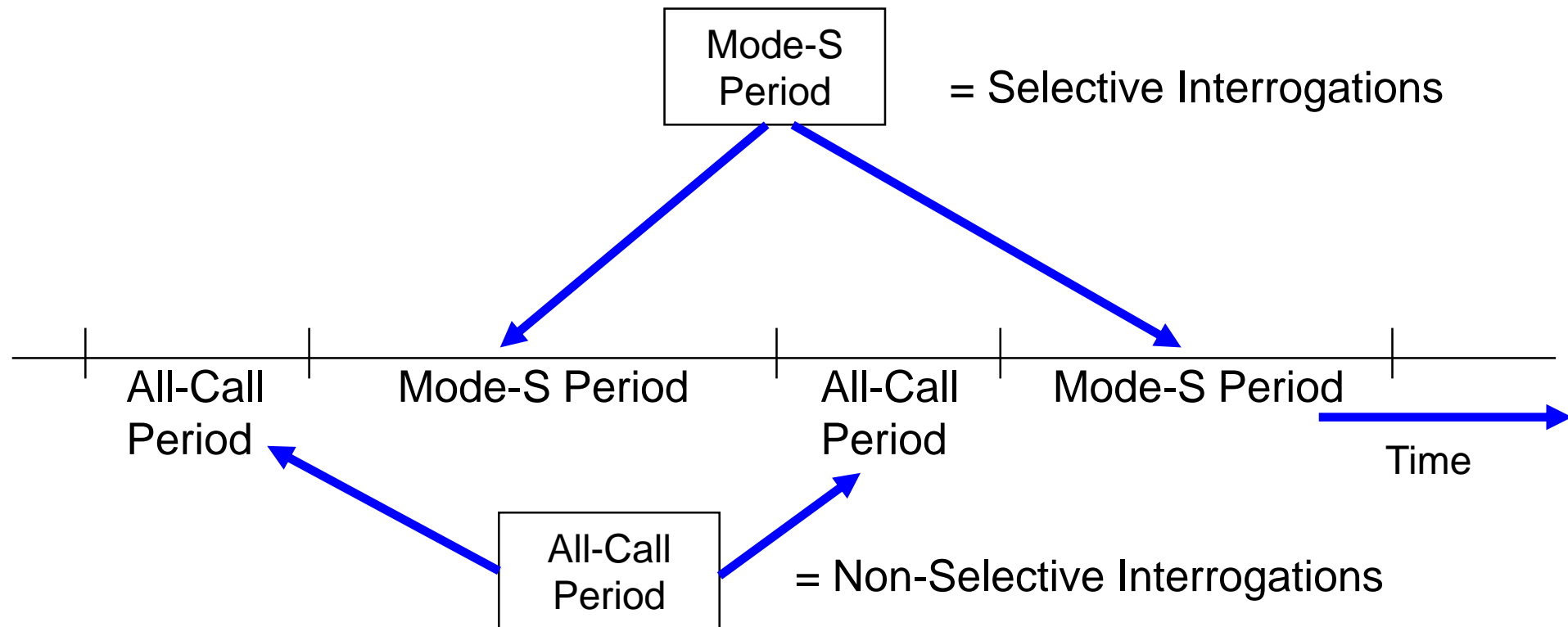
Surveillance Reply (DF 4 or 5) – Short: 56 Bits (no BDS extraction)



Comm-B Reply (DF 20 or 21) – Long: 112 Bits (content of BDS – MB:56)

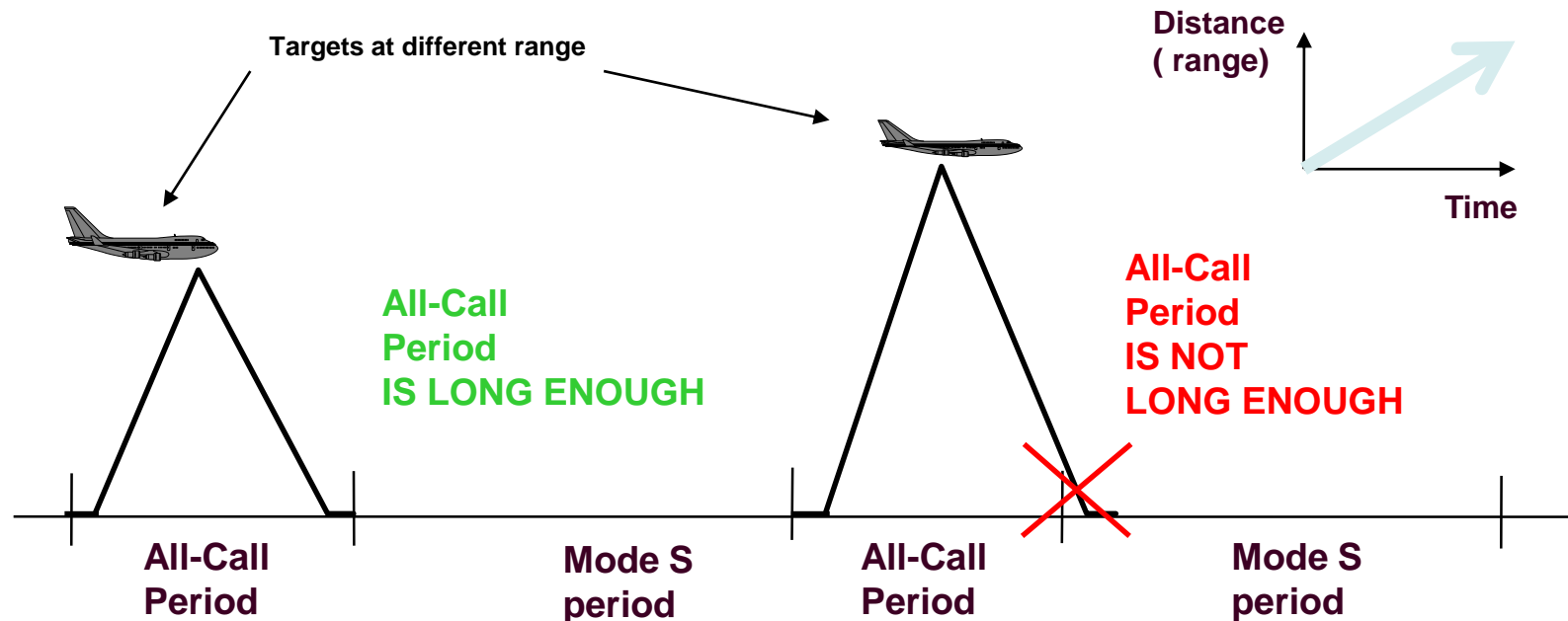


All-Call Period vs. Mode-S Period (1)



Note: The Mode S Period is also known as the Roll-Call Period

All-Call Period vs. Mode S Period (2)



The length of the All-Call period must be AT LEAST long enough to allow an all-call interrogation and reply sequence to complete (radar range).
More information in "Radar programming – MIP"

Mode S and Mode AC all-calls can be sent in the same All-Call period

Elementary Surveillance (ELS)

- Basic Surveillance functionality
 - 24-bit technical identification
 - Mode A code
 - Altitude reporting to 25ft (Mode C)
 - Transponder capability reports
 - Datalink capability report (BDS 1,0)
 - Common usage GICB report (BDS 1,7)
 - Aircraft Identification - call sign (BDS 2,0)
 - Flight status (airborne / on the ground)
 - Including Emergency situations + SPI
 - SI-Code functionality

ELS Registers

- The BDS registers required for Elementary surveillance are:
 - BDS 1,0 – Data Link Capability Report
 - BDS 1,7 – Common Usage GICB Capability Report and
 - BDS 2,0 – Aircraft Identification
- The provision of these registers is mandated for all aircraft
- These registers are requested in the first selective interrogations
 - typically 3 selective interrogations in the same beam once the aircraft is acquired
- The content of these registers should not change under normal flight conditions
 - If it does, it should be broadcasted
- EHS register availability known from BDS 1,7

Enhanced Surveillance (EHS)

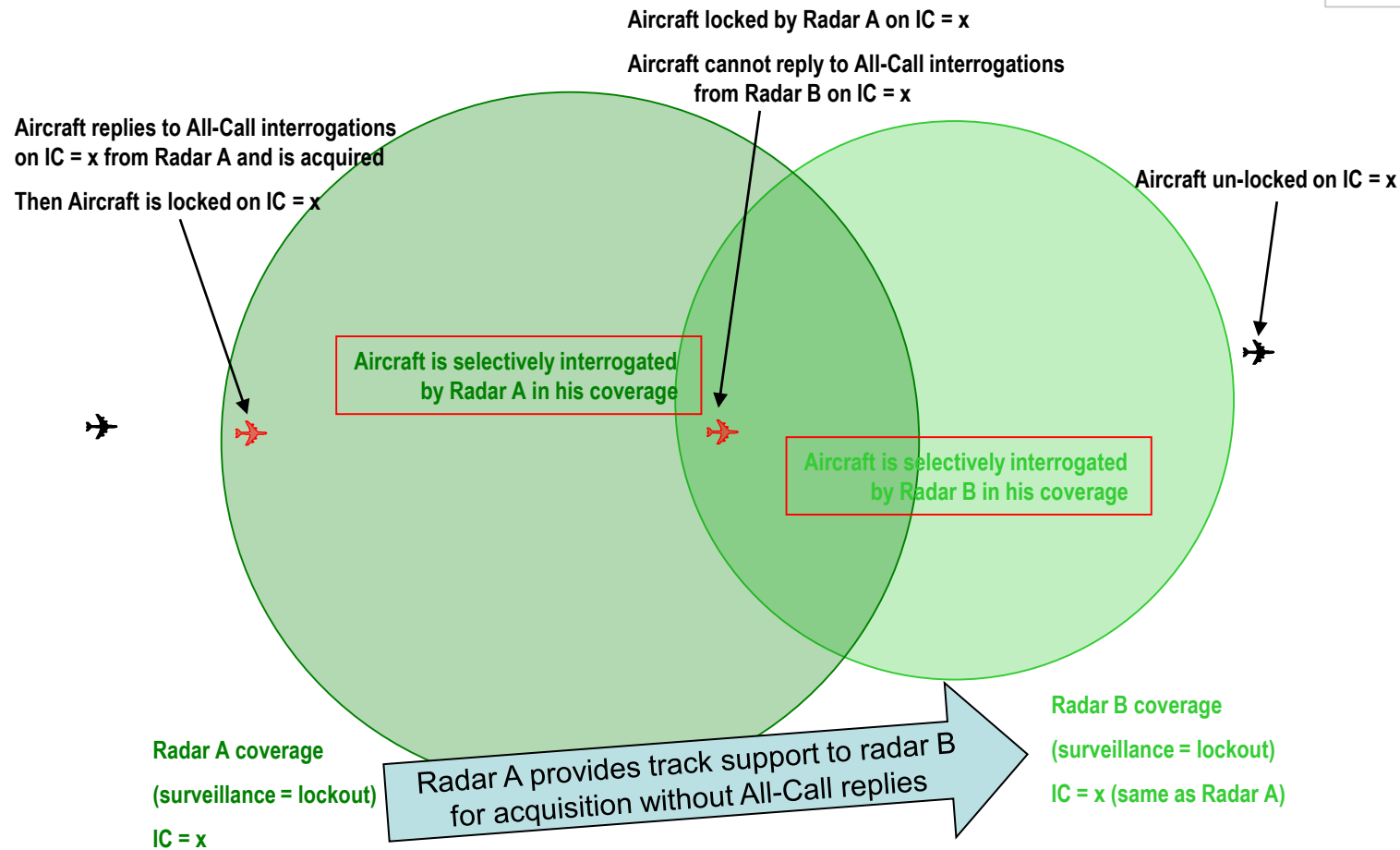
- 3 BDS registers are in general regularly extracted
 - BDS 4,0 - Selected Vertical Intention
 - Selected Altitude
 - Barometric Pressure Settings
 - BDS 5,0 – Track and Turn
 - Roll Angle
 - True Track Angle
 - Ground Speed
 - Track Angle Rate
 - True Airspeed
 - BDS 6,0 - Heading and Speed
 - Magnetic Heading
 - Indicated Airspeed
 - Mach
 - Barometric Altitude Rate
 - Inertial Vertical Rate

Cluster – operating stations together

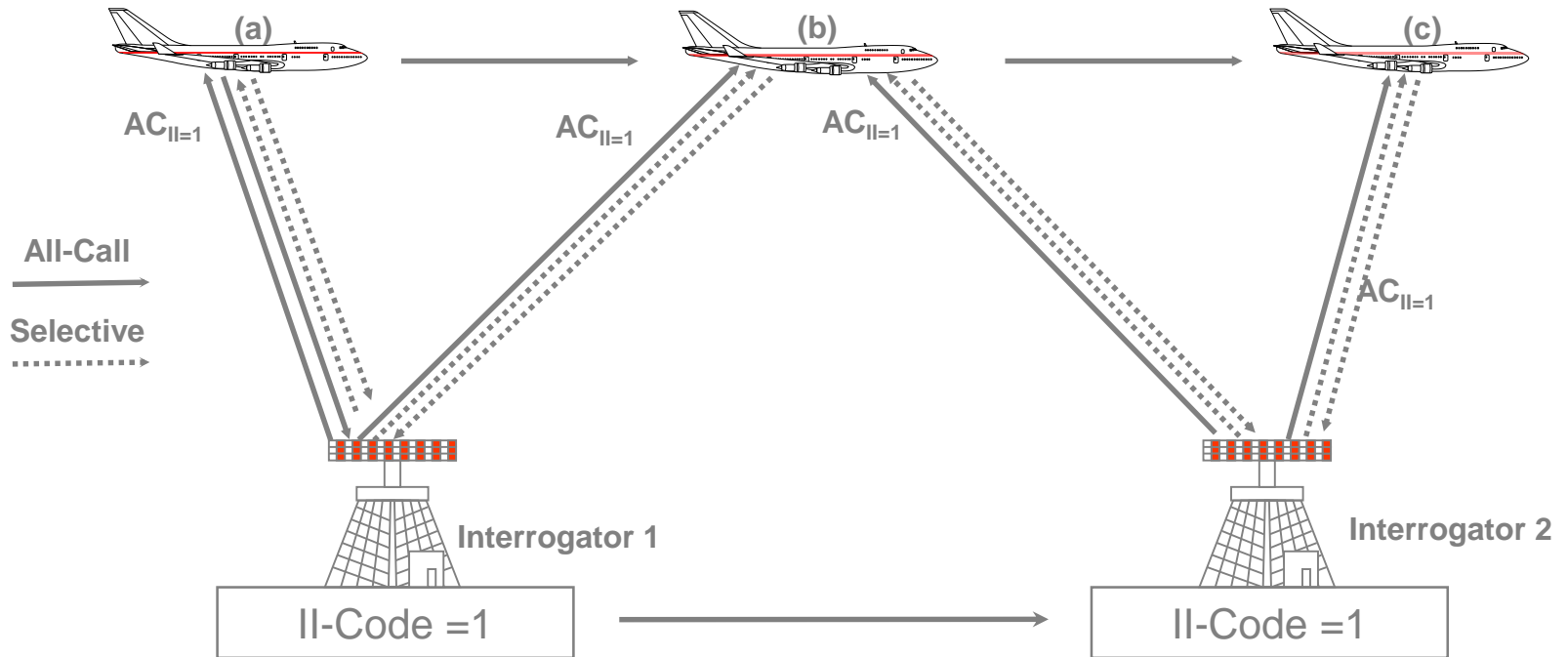


If an aircraft is in the cover of several radars, then they could share that information via ground data links.

Cluster Principle (1)

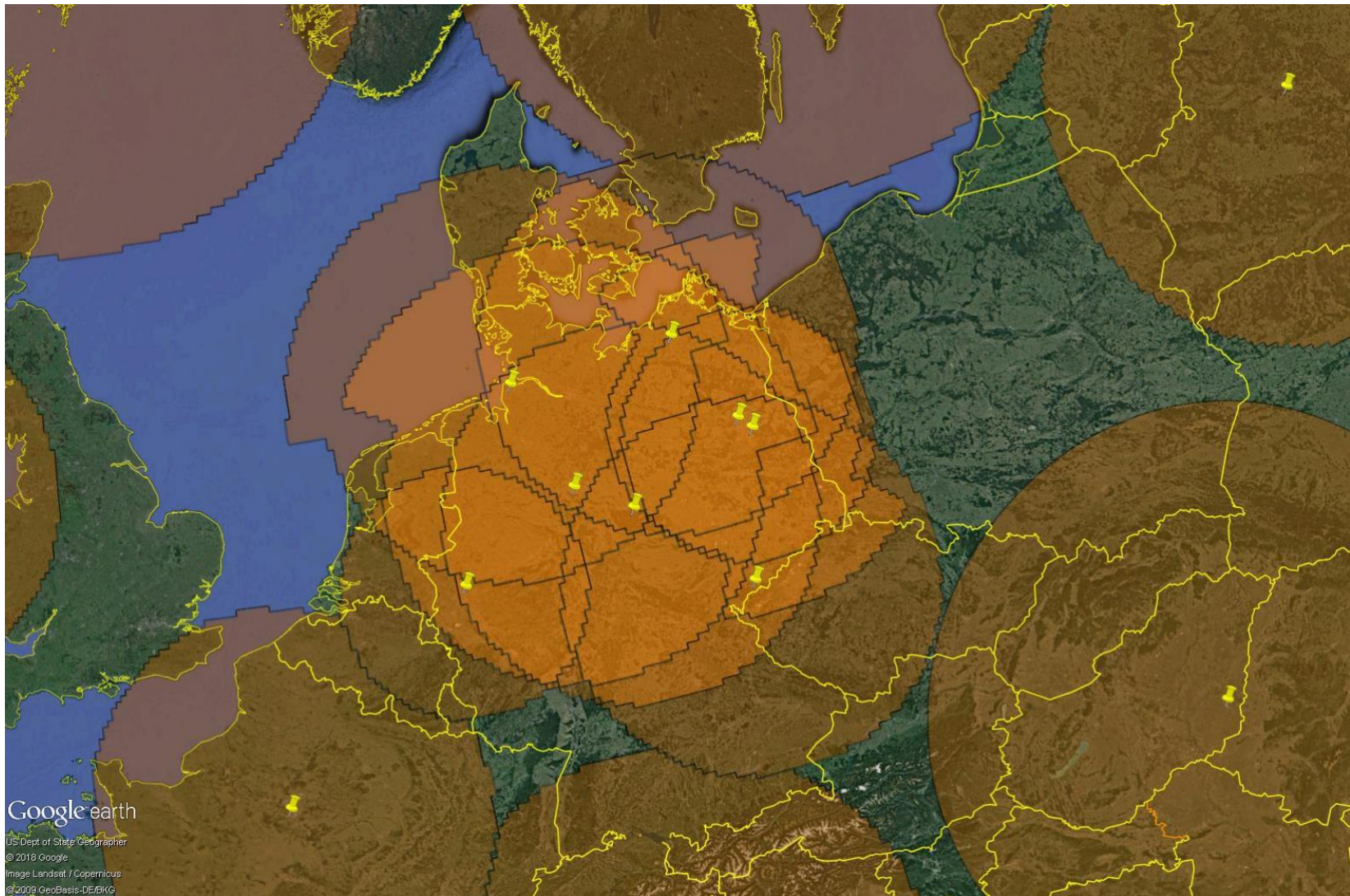


Cluster Principle (2)



Radar 1 provides track support to radar 2 for acquisition without All-Call replies

Example of Cluster



ACAS / TCAS

- Airborne Collision Avoidance System (ACAS)
- Traffic alert and Collision Avoidance System (TCAS)
 - TCAS is an airborne device
 - Requires a Mode S transponder on-board
- TCAS provides collision avoidance protection
 - Traffic Advisories – visual acquisition of intruder aircraft
 - Resolution Advisory – recommended escape manoeuvres in the vertical dimension
- TCAS relies on Acquisition Squitters to acquire aircrafts in vicinity

TCAS Active Surveillance

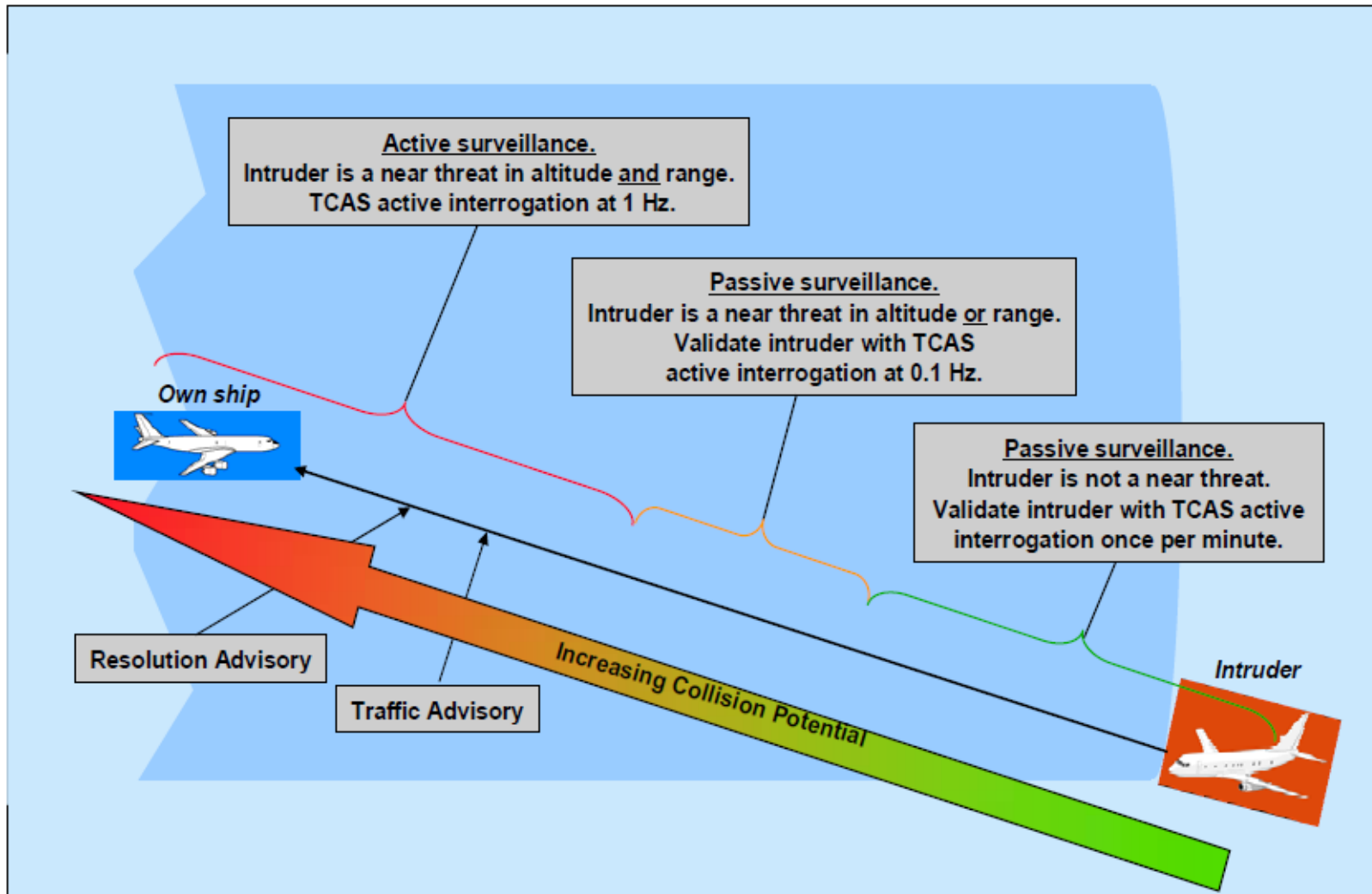
- TCAS sends Mode S interrogations (UF 0) to the acquired aircraft (intruder) to get the range, bearing and altitude
- The transponder of the acquired aircraft replies with a DF 0, containing its altitude
- The rate of TCAS interrogations to a Mode S aircraft depends on the range and the closure rate.
 - Between 1 interrogation every 5 seconds and 1 interrogation per second

TCAS Hybrid Surveillance (DO-300)

- TCAS with Hybrid Surveillance use passive surveillance to track intruders not in near-term collision
 - Use valid barometric altitude and position received in DF17 Extended Squitters to acquire and monitor the aircraft
 - Decrease Mode S surveillance interrogations done by TCAS (UF 0) and replies (DF 0)
 - Once the intruder come close to being a collision threat, it is tracked with active surveillance

- Aircraft not broadcasting DF17 Extended Squitters are tracked actively

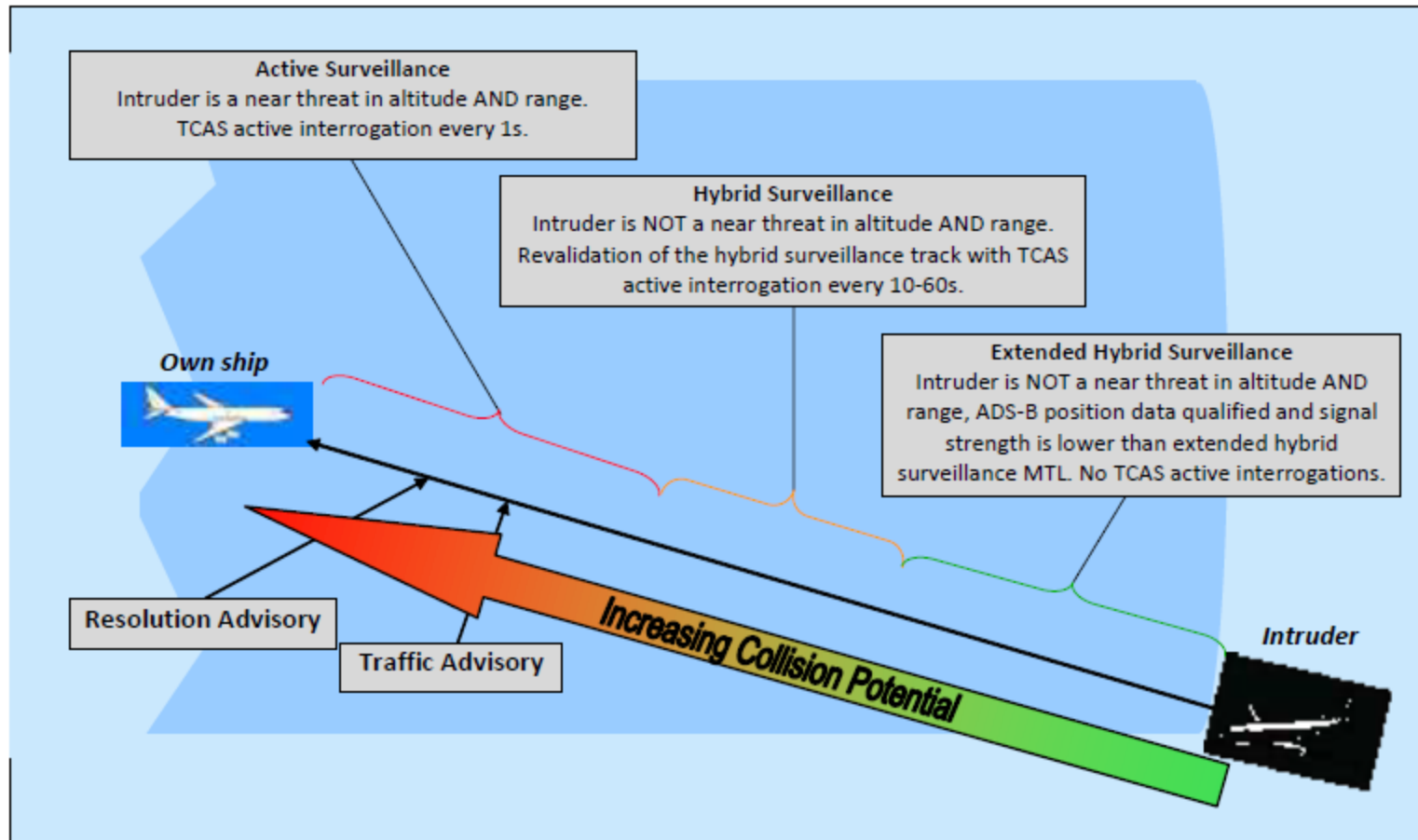
DO-300 – Hybrid Surveillance



TCAS Extended Hybrid Surveillance (Future)

- TCAS use DF17 Extended Squitters (ADS-B) to acquire and monitor the aircraft
 - Decrease the number of interrogations (UF 0) and replies (DF 0)
 - No interrogations in Extended Hybrid Surveillance (passive)
 - Depends on data quality and ADS-B Version Number
 - Extended Hybrid Surveillance if ADS-B Version Number ≥ 2

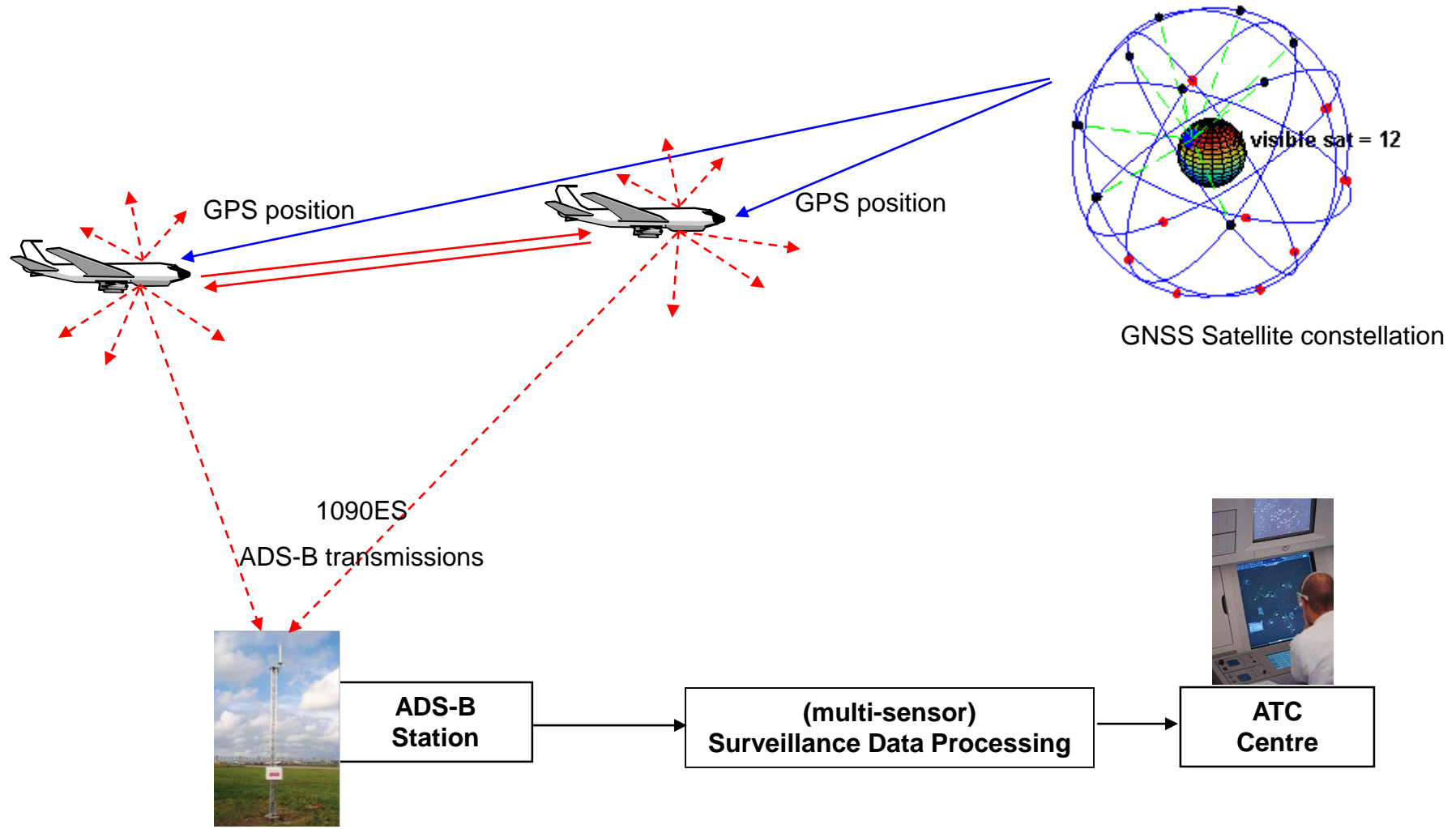
DO-300A – Extended Hybrid Surveillance



TCAS Resolution Advisory

- In case of Resolution Advisory, long Mode S messages are exchanges for coordination:
 - TCAS interrogations: UF 16
 - Transponder replies: DF 16

ADS-B : Automatic Dependent Surveillance-Broadcast



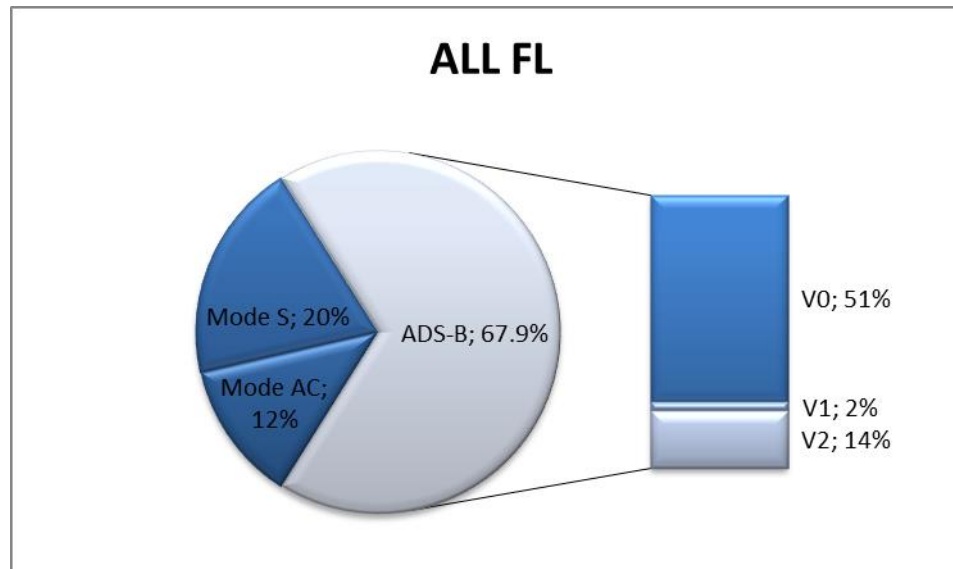
ADS-B

- Broadcast per aircraft of parameters
 - DF17 Extended Squitters (long Mode S message) on 1090MHz
- When aircraft is airborne, typically
 - Airborne position – 2 per second
 - Airborne Velocity – 2 per second
 - ACID – 1 every 5 seconds
 - Max 6.2 extended squitters per second
- For vehicles without transponder
 - DF18 Extended Squitter is used to broadcast parameters

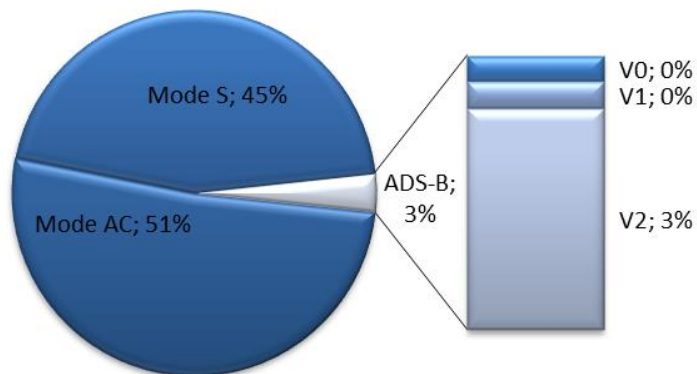
ADS-B Equipage

- Not all aircraft are equipped with ADS-B
- Different versions of ADS-B
 - v0 and v1 have very few quality indicators
 - The position may not be reliable
 - v2 provides good position indicators

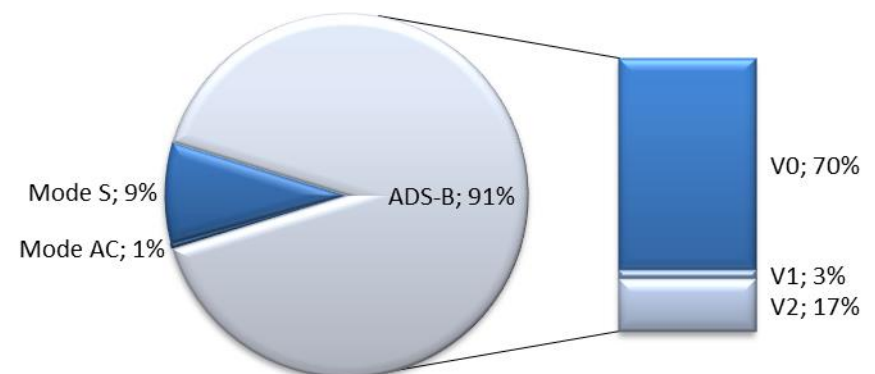
SUR Equipage per flight over Paris 2018



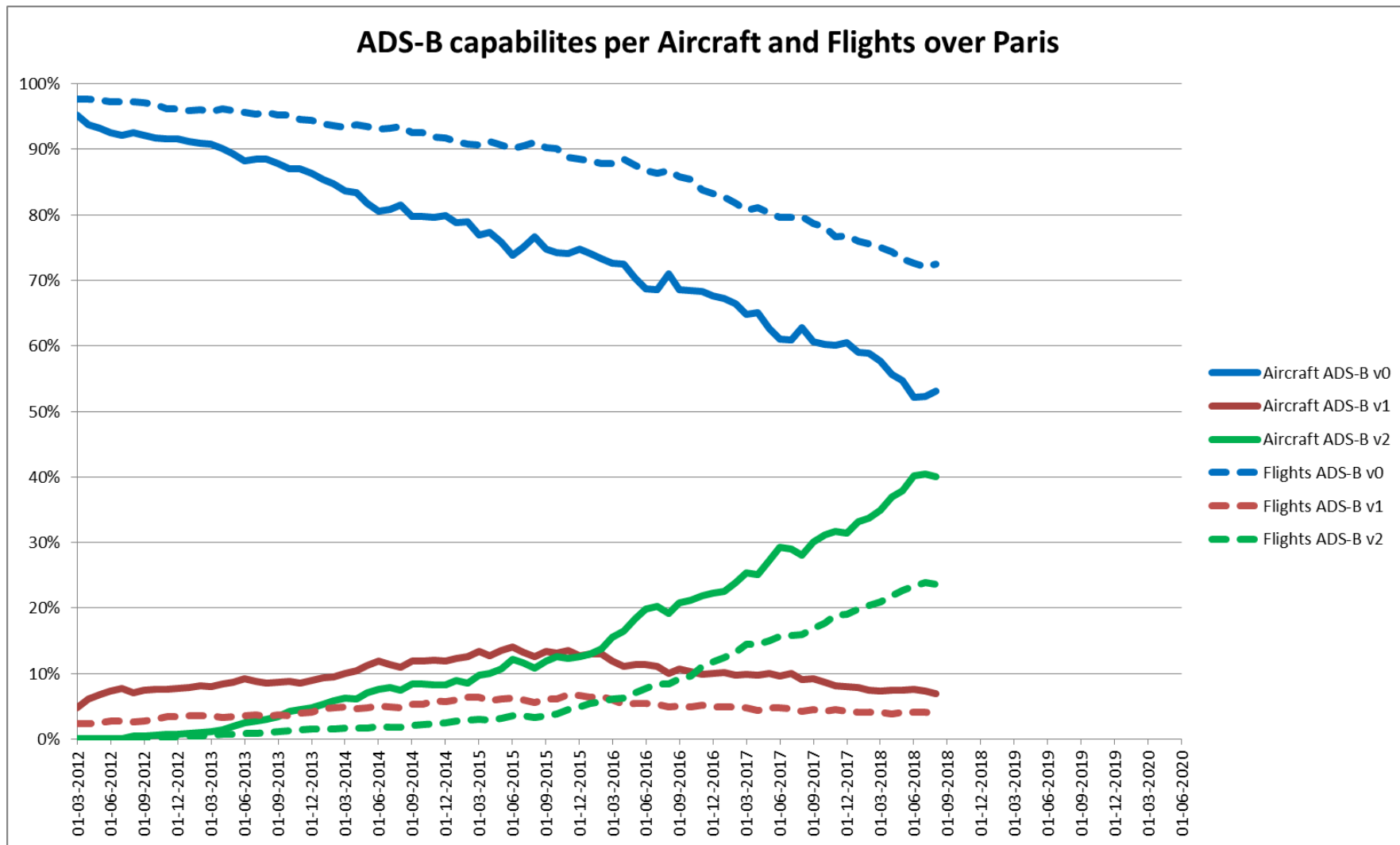
Flights Only Operating Below FL150



Flights Operating Above FL250



ADS-B Surveillance Equipage Evolution



Multilateration

- Signal transmitted by aircraft transponder and received at several sensors
 - Time Difference of Arrival (TDOA) measurements by ground sensors
 - Central processor calculates aircraft position
- Multi-Lateration is common in Europe
 - Mainly uses squitters for deriving position
 - Mainly short range systems at airport
 - Wide area systems are emerging
- Active interrogation is common



Station Hranicky

Transmitter antenna

Receiver antenna

GPS antenna

Active Multilateration Systems

- **Independent** of existing infrastructure
- **Improved detection** of Mode A/C only aircraft
- **Complementary** information to position (Mode A, Mode C, A/C ID)
- **Increase accuracy** at long range
- Care must be taken
 - not to generate excess 1030/1090MHz FRUIT
 - not to over occupy the Transponder (due to selective interrogations)