IoT4EO - The ESOC perspective

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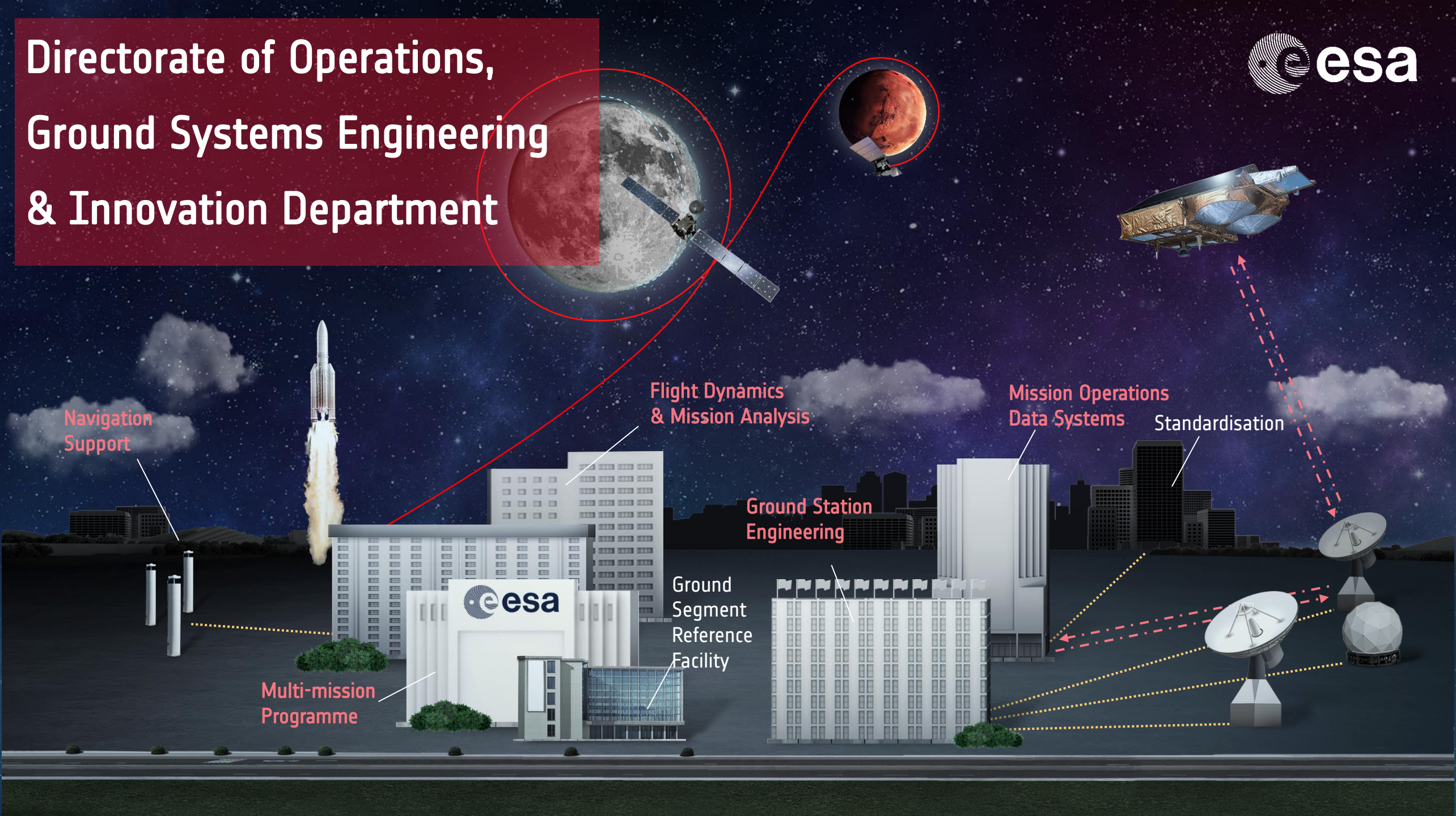


Assumed scenario:

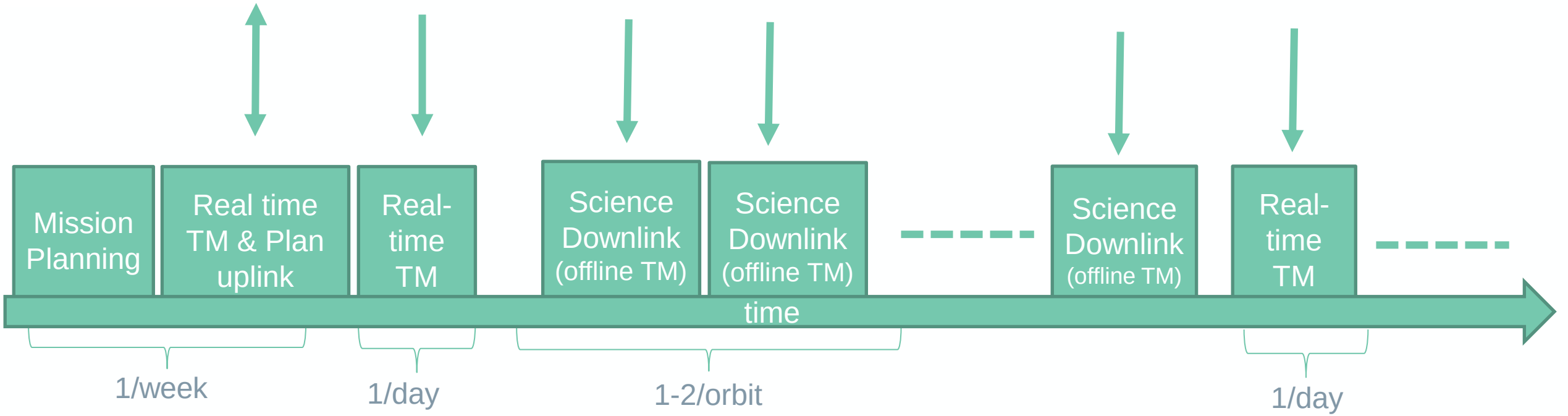
Continuous connectivity via a combination of Space-to-ground direct links or relays (LEO/MEO/GEO) with very low bandwidth (~ 1 kbps), with latency in order of a few seconds or less.

Question

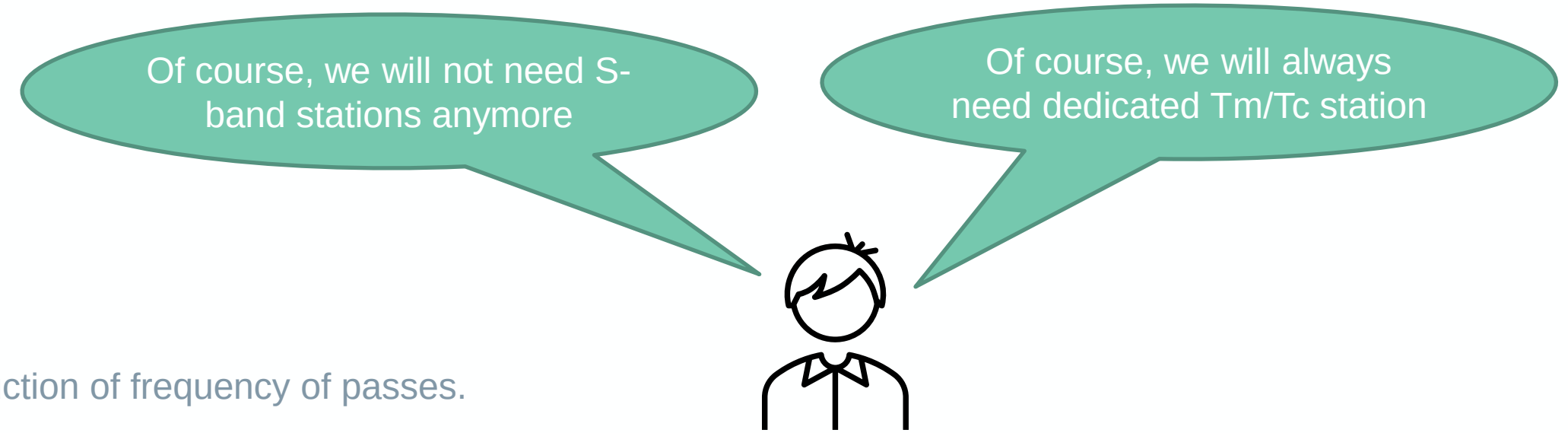
What is the impact on Spacecraft Operations and (Flight Operations) Ground Segment Engineering for typical ESA mission?

These are my views, based on interviews with colleagues.

The story starts with today

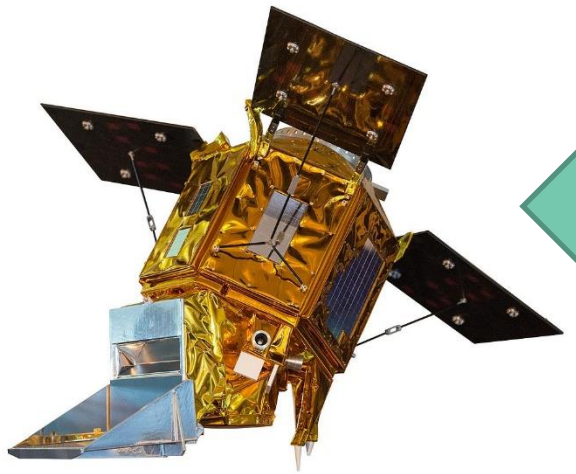


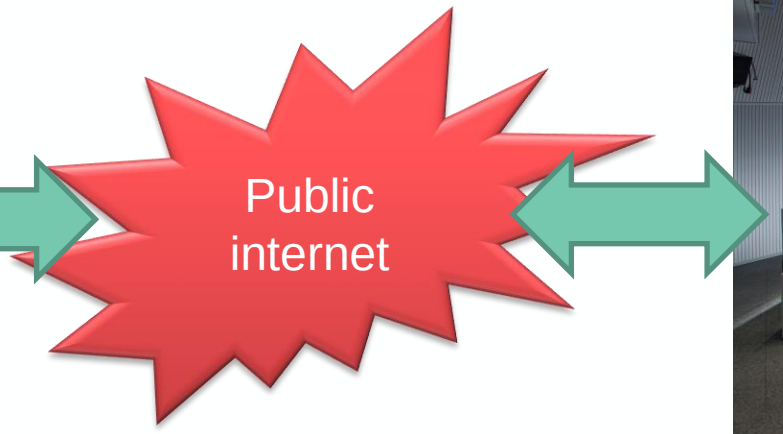
S-band Architecture



- Reduction of frequency of passes.
  - From 1 pass per day to 1 pass per week?
- Speed up the phase out of S-Band station network?
  - Also bulk commanding needed. → Mission Timeline uploads, memory images etc…
  - So probably still need a “powerful” TC upload capability.
  - Certain type of anomaly recoveries, need lots of TM/TC capabilities.
- Still need bulk TM download of cyclic recorded TM for offline analyses and post-operation processing at ground.
- Most concluded: We’ll probably still need them!

Satellite operational systems coming out of the basement



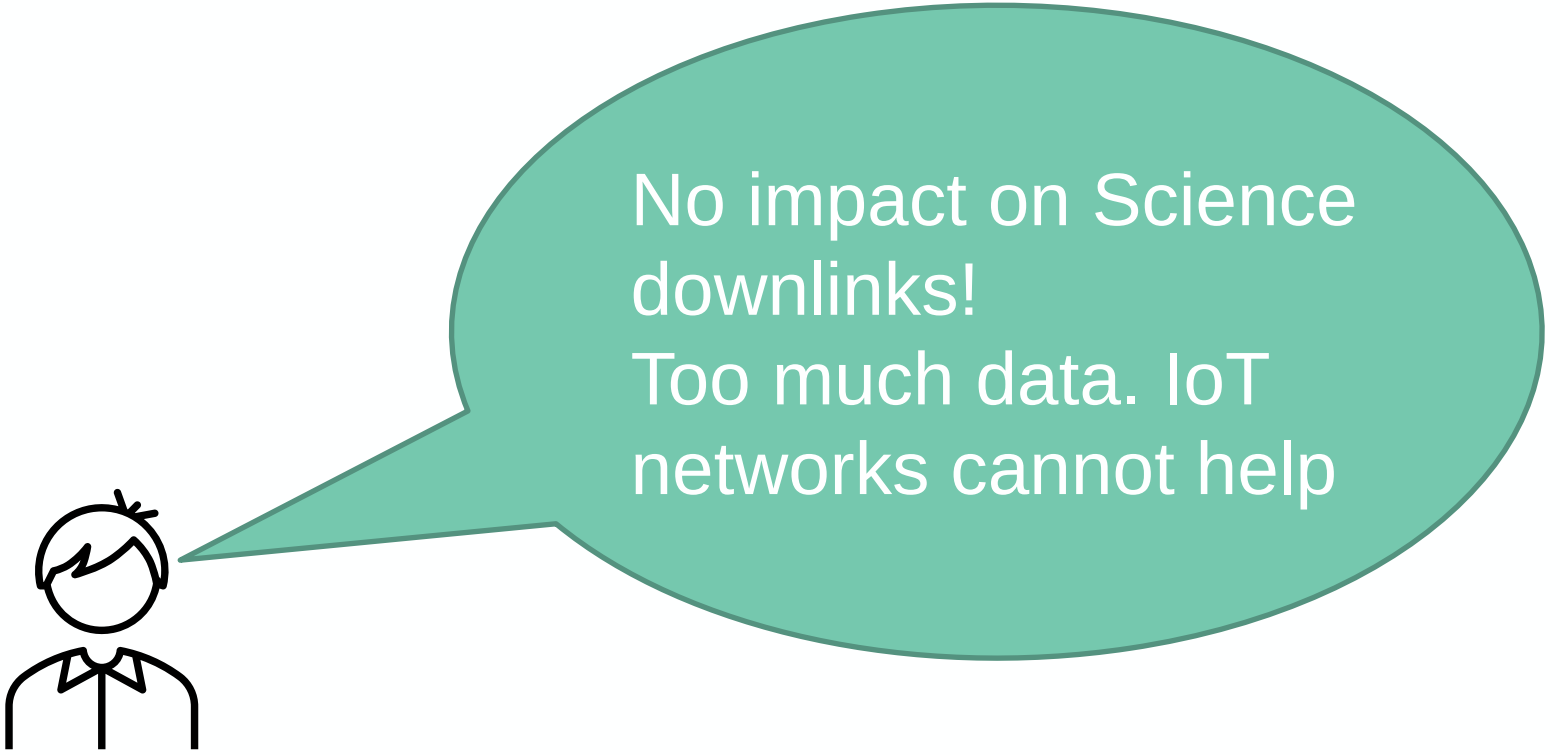


- No more hiding behind firewalls on dedicated networks, fences, dedicated lines, physical layer protection.
- No more security by obscurity or “my antenna is bigger than yours” approach….
- Data arrive via internet, hence directly into cloud providers, so let’s process it out there as well
- To be analysed: Compatibility with existing protocols
  - ECSS Packet Utilization Standard (PUS) over IoT
  - CCSDS Mission Operation services (MO) over IoT OK?
  - File Based Operations (CFDP) and Delay Tolerant Network (DTN) over IoT OK?

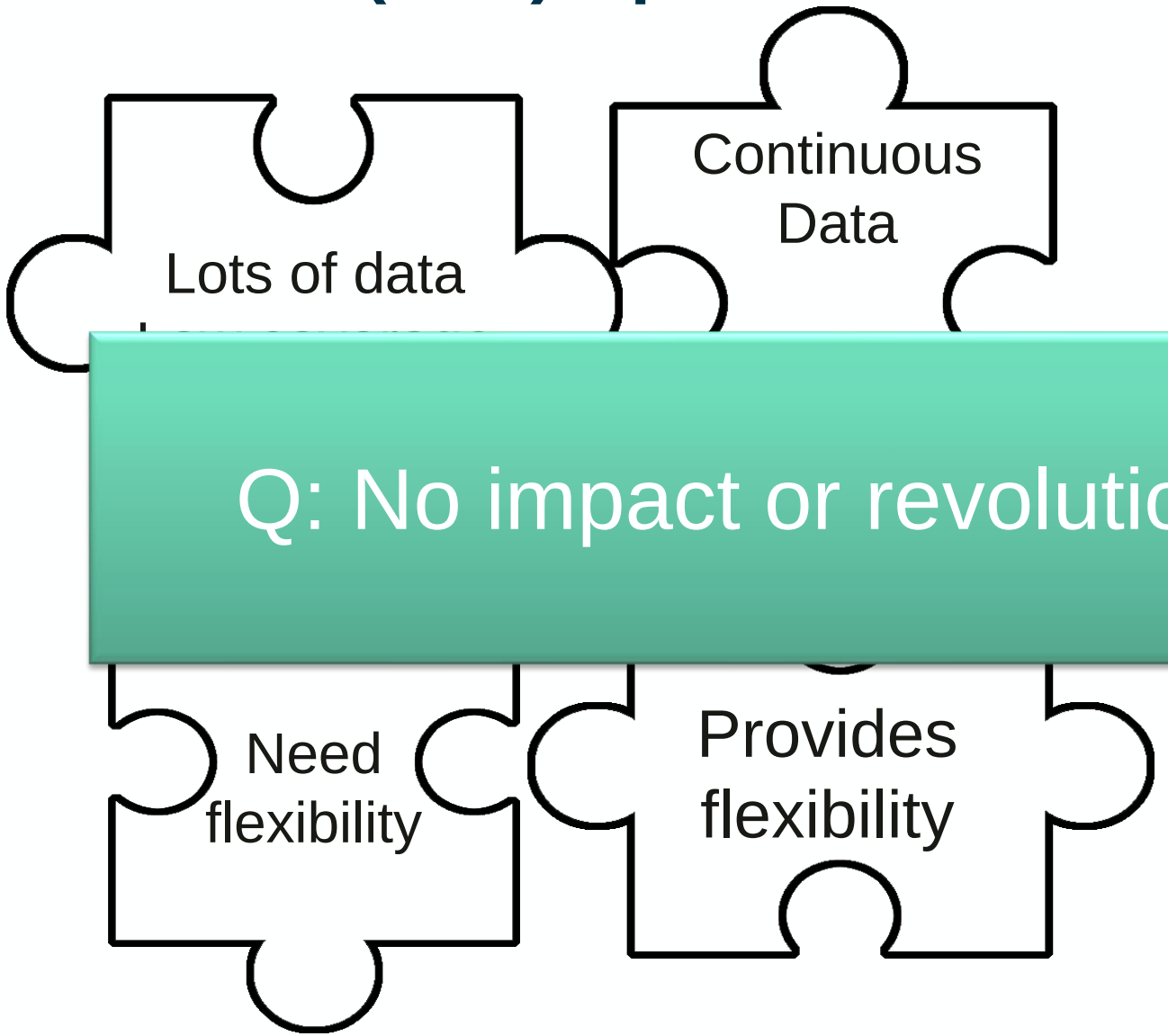
Security

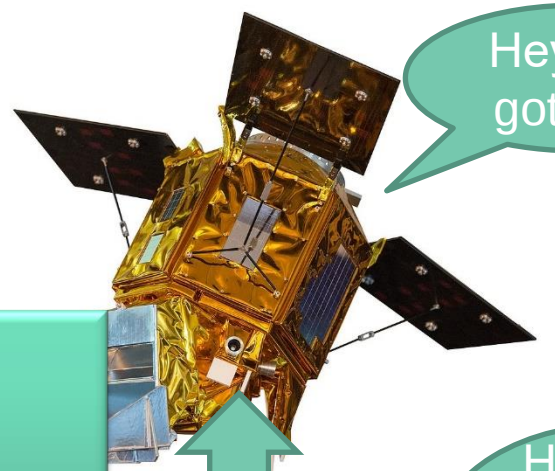
- Data link security protocols
  - Typical ground-space link baseline is application of CCSDS Space Datalink Security Protocol **mainly for TC Authentication** only – this is based on symmetric encryption and secret key infrastructure → Not for IoT devices?
  - With IoT concepts of bi-directional and distributed / internet-like commanding and reception
    - **Both TM and TC Authenticated Encryption needs** (though subject to individual mission security assessment)
  - Protocol selection for IoT concepts must account for security as part of trade-off
- Application layer security
  - Protocol closure concepts (including those for security) likely to be impacted (e.g. CFDP / FBO)
  - Recommended to explore re-use of 5G/6G and associated security guarantees
- IoT security specifics
  - IoT security in general a hot topic of active R&D and standardisation with a number of publications
  - Resource-constrained devices require lightweight cryptographic algorithms/functions
- Ground system security architecture
  - Much **more distributed ground nodes** demand revised security operations concept and automation associated with **Chain of Trust, Public Key Infrastructure, Key Management, Certificates Management.**
    - Security orchestration potentially becomes additional points of failures for the system
  - Loss of typical physical facility protections of standard ground station network
    - Must assume physical access/tampering possible for IoT devices

… and then what about the science download?



Direct-to-earth(DTE) Optical + IoT





Hey, I've got data

Hey, I've good weather and time

Distributed, decentralized, autonomous optical ground station

Reliability and vendor lock in

- Usage by ESA would require concepts to avoid vendor lock in:
  - International interoperability communication standards
  - Software Defined Radio (SDR) allowing connection to several network providers with same S/C HW.
- Positive side effect: Opens up for a real competitive marked:
  - Swap providers, like you do with your mobile, depending on price.
  - Load balancing, ie. swap according to resource utilization.
- Allows ESA to act as anchor customer for small new constellation in parallel with more established.
  - No need for a single provider with full coverage to embark.

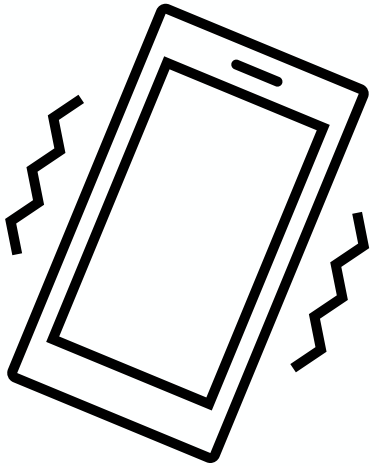
Others say: Well, we're having a contract with GS provider X today, so we can also in the future stay with one provider.

→ Like buying a mobile that only works with one provider!?!

But how do we operate?

From “Schedulable” to “when needed”

Assumption: IoT will provide some sort of pay-per-use service similar to mobile phones.



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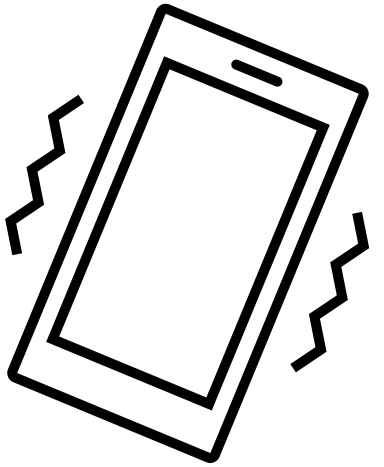
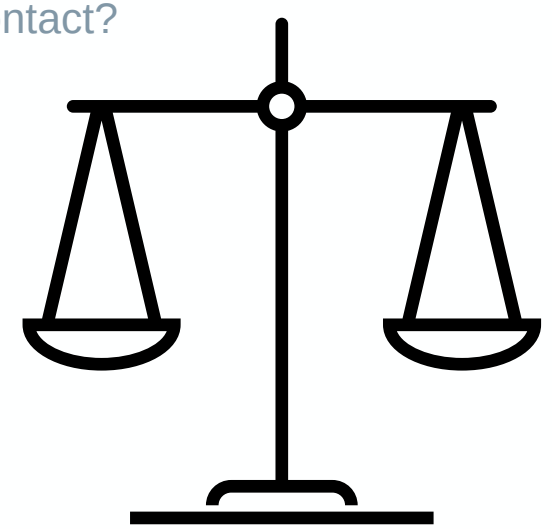


- Shift from doing stuff when contact allows to on-request interaction when needed due to some operational need.
- Need to move away from frequent cyclic/scheduled status reporting
    - This is for offline purposes of forensic investigations only, downloaded as piggyback on science data

- Require on-board autonomy to know when to contact ground.
    - Satellite calling-home ability
    - Already current FDIR systems identify critical events.
- Verification of critical events onboard. Did it take place?
- Informing ground of decisions taken by onboard by AI
    - Example: Image not taken due to cloud, send the request to somebody else.

More or less autonomy?

- Traditional measure of Autonomy: How many hours can the spacecraft be without ground contact?
- Currently designed to survive without ground contact
    - This capability will still be needed (in case of problems with comms etc…)
- Designed to minimize ground contacts



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- Traditional measure of Autonomy: How many hours can the spacecraft be without ground contact?
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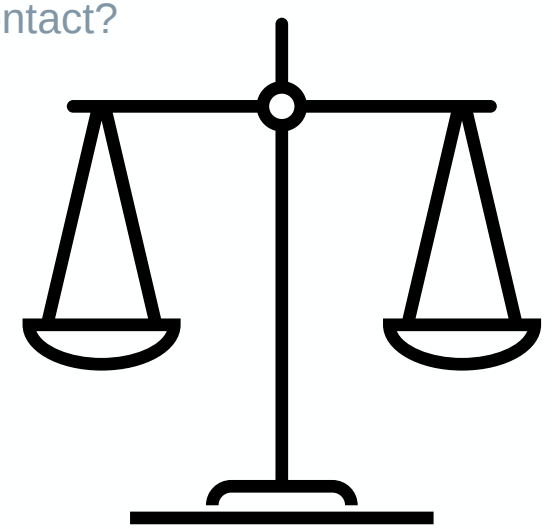
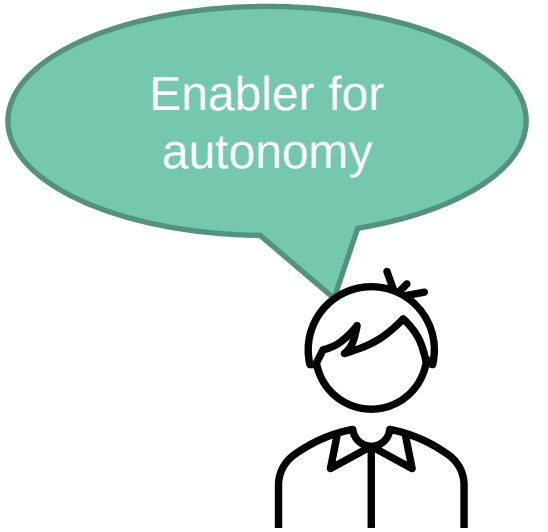
- Designed to minimize ground contacts (ie. maximum rigid)



Now:

- Require flexibility to accept replanning/rescheduling
- Satellite “as web server” → Moving control features onboard →
    - Moving from uplinking commands to goal oriented commanding → More Autonomy.
    - Lowers the entry barrier for on-board autonomy → Gradual improvements.
- A bit perpendicular the amount of autonomy onboard
    - More intelligence in reporting. Ability to synthesise information.
- LunaCOMM context – how to initiate “user initiated” services?
    - Specific beacon signals are discussed to initiate services? Use case for IoT?
    - Messaging services (Luna “SMS”/”SOS” service), emergency messages (Space weather)?



Impact on Mission Planning concepts

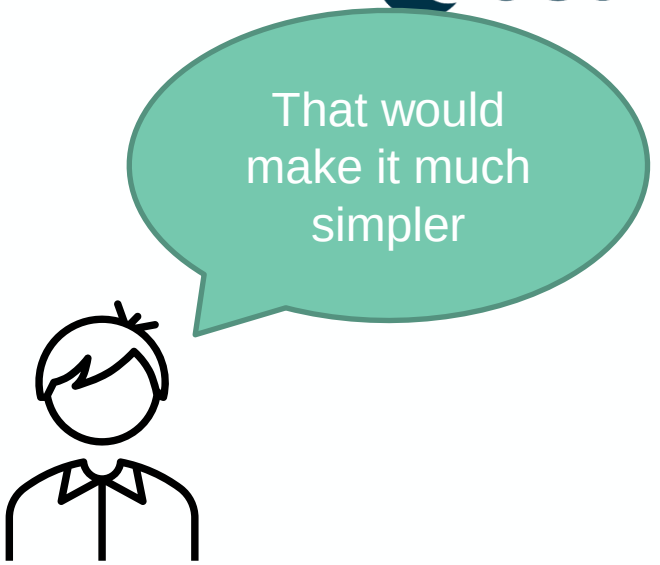
- Significant complexity of current MPS concepts are planning/scheduling/execution of GS passes
  - Still required for science download and bulk uplinks.
  - Becomes obsolete for nominal platform operations
- Calls for increased flexibility
  - Continuous and Opportunistic replanning
  - New interaction patterns between on-ground and on-board planning.
- Combination of IoT and new Planning and Scheduling concepts enables new opportunities.
  - Need coordinated investments in both areas

- Enable urgent/emergency/time critical services

Simplify life

- Scheduling of Collision avoidance manoeuvres?
  - Go up / go down selection at short notice.
  - Decrease reaction time. Removes dependency of GS passes

  → Allow automation, simpler coordination.



- LEOP Ground station network of S-band stations for constellations?
  - No need for GS for orbit determination (ranging, angles, doppler measurements) when IoT can provide the GNSS position&timing solution directly.
  - May still need a LEOP network as less passes would require more autonomy onboard.
  - Enable multi-satellite launches allowing to waive requirements to see all satellites within Xh after launch.
    - Already for SWARM, extra antenna to allow seeing all missions shortly after launch.

New opportunities

- Satellites with very driving orbits, like Very low LEO (VLEO)
    - Aeolus@320km requires orbit predictions to the ground stations 4x per day today to ensure aquation of signal at GS.

- Accelerate adoption of standard IT solutions for space (“Web server on board”)

- Would Optical+IoT be sufficient to not need traditional RF?

- Inter-satellite-links(ISL) & IoT for LEOP scenarios with multiple launches, to reduce number of GS passes needed.

Summary:

Operations of Satellite in the Age of IoT will resemble more operation of a network of flying computers, rather than today's spacecraft ops.

- I have a dream -

ESA to fly innovative experimental communication terminals on our main flagship missions, to inspire and accelerate innovation

Announcement of opportunity

ESA/ESOC is searching for a PostDoc Research Fellow to work on impact of IoT on operations and ground segments.

VN will be published soon on https://jobs.esa.int/

We would like to hear about your cool research ideas!