# THOR – A Mobile, Free Space, Optical Network

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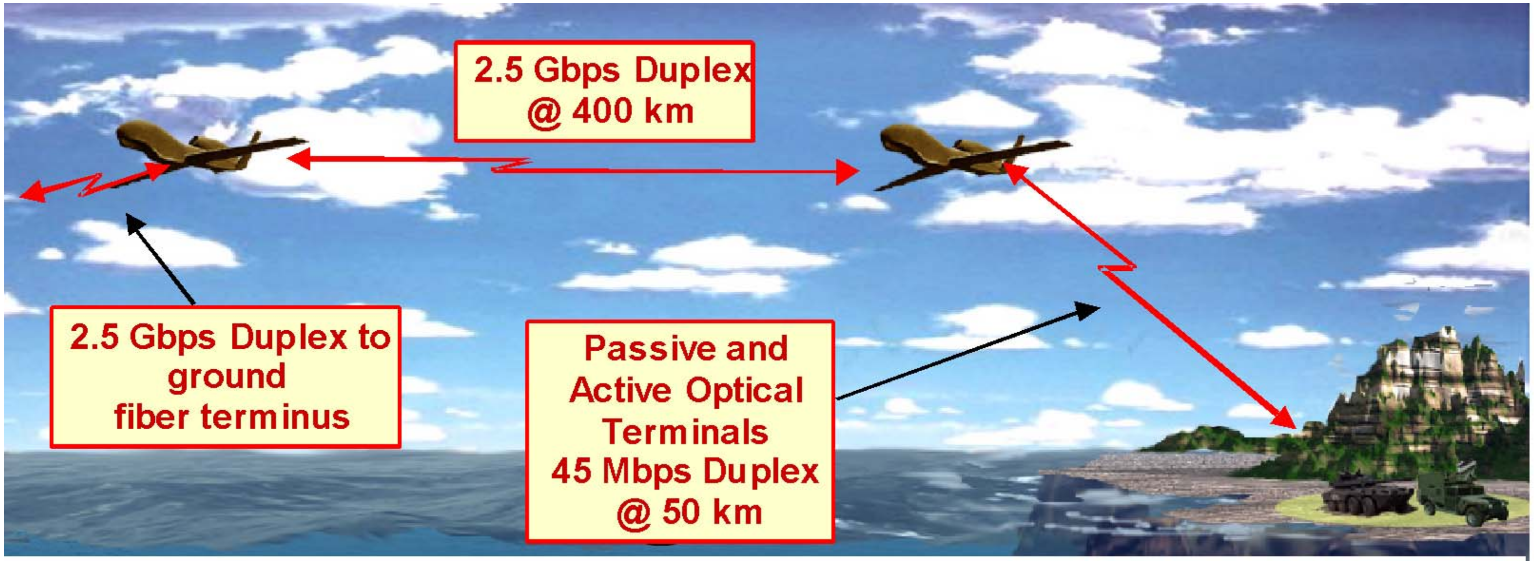
# Outline

- Introduction
- The THOR optical network
  - Characteristics
- Major issues in free space optical, mobile networks
  - Physical layer
  - Network layer
- Potential solutions
- Summary

# THOR Vision

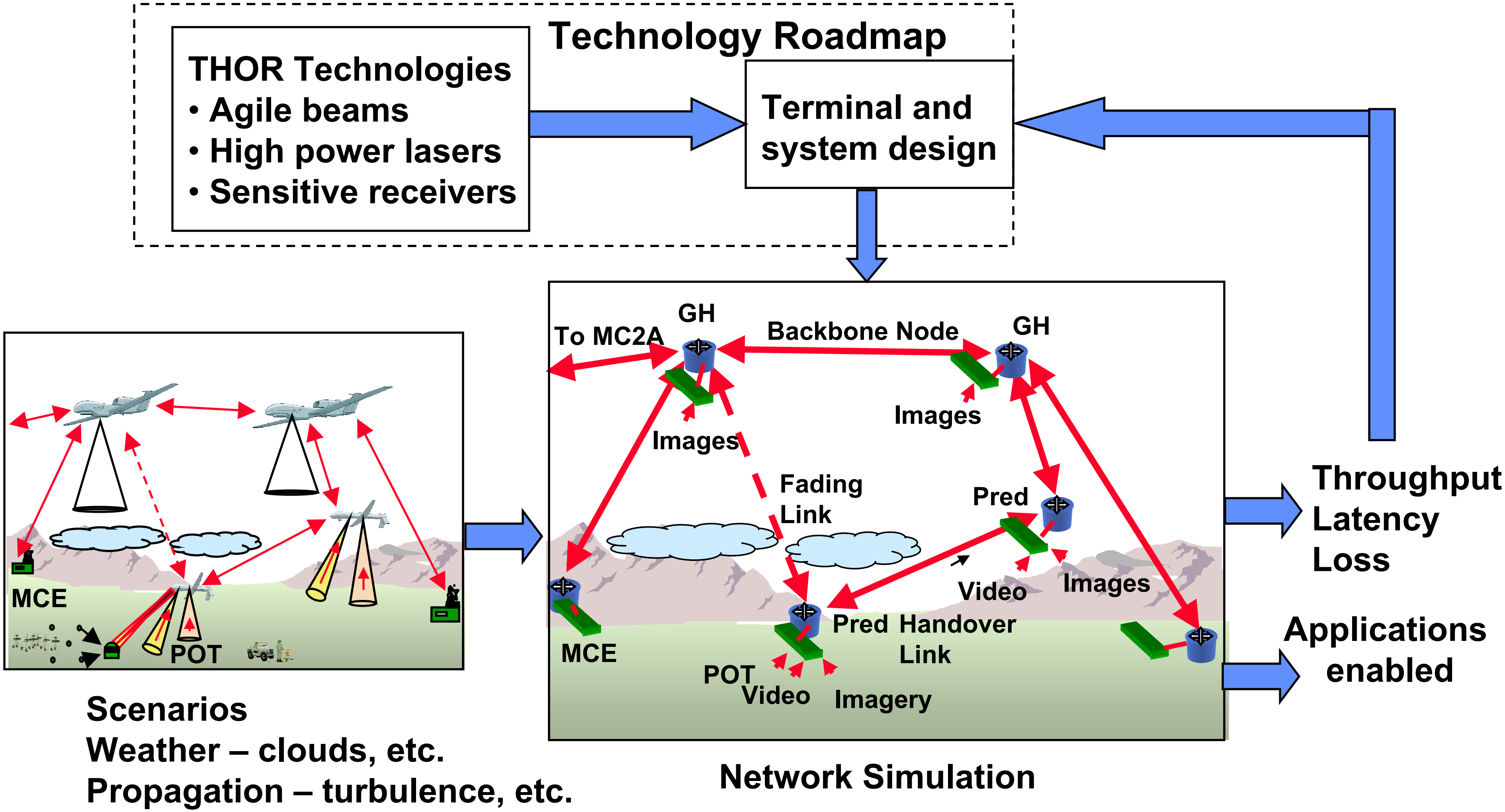



- Bring broadband communications to the theater of operations
  - "Fat pipe into/out of theater"
- Key characteristics of THOR network
  - Optical network
    - Mobile, ad hoc network
    - Primarily airborne nodes
  - Primarily digital data
    - Sensor data

# THOR Notional "Requirements"

| | Phase 1 - 2/03<br>Enabling Technologies | Phase 2A - 12/03<br>Subsystems | Phase 2 B - 10/04<br>Subsystems | Phase 3 - 10/05<br>System |
|---|---|---|---|---|
| Latency<br>• Sensor feed<br>• File transfer<br>• Video and voice | < 2 seconds, 14 regeneration hops | < 1 second, 8 regeneration hops | < 500 msec, 6 regeneration hops | < 150 msec, 5 regeneration hops<br>Sufficient for video and voice over 400 km |
| Active Link Performance | • Data rate 2.0 Gbps<br>• BER 10-9<br>• Range 100 km<br>• Link margin 5 dB | • Data rate 2.0 Gbps<br>• BER 10-9<br>• Range 200 km<br>• Link margin 6 dB | • Data rate 8.0 Gbps<br>• BER 10-9<br>• Range 300 km<br>• Link margin 24 dB | • Data rate 8.0 Gbps<br>• BER 10-9<br>• Range 400 km<br>• Link margin 33 dB |
| Passive Link Performance | • Data rate 200 Mbps<br>• BER 10-9<br>• Range 12 km<br>• Link margin 15 dB | • Data rate 200 Mbps<br>• BER 10-9<br>• Range 25 km<br>• Link margin 17 dB | • Data rate 800 Mbps<br>• BER 10-9<br>• Range 37 km<br>• Link margin 15 dB | • Data rate 800Mbps<br>• BER 10-9<br>• Range 50 km<br>• Link margin 20 dB |

# System Engineering and Network Architecture



# How Is THOR Used?

- **THOR is only part of the entire theater communications network**
  - **THOR optical links do not replace RF links**
- **THOR supports the extraction of extremely broadband data from sensors such as SAR and multispectral imagers**
  - **The largest fraction of THOR network bandwidth is associated with sensor data streams**
- **THOR optical terminals are at major command levels**
- **THOR network cost will be driven by the number of air vehicles required and the complexity and number of node ports required per air vehicle**

# THOR Physical Layer Issues

- Available telecommunications technology
  - Lasers, modulators, amplifiers, detectors, telescope, beam steering
  - Develop THOR specific optical communications technology
    - High power laser amplifiers, sensitive receivers, advanced beam steering techniques, passive optical terminal
- Atmospheric transmittance
  - Select waveband to avoid atmospheric absorption loss and dispersion
  - Robust links
- Atmospheric turbulence
  - Minimize aperture or use adaptive optics
  - Interleaving and coding
  - Robust links
- Aircraft induced turbulence
  - Aperture location
  - Field of regard
- Cloud and terrain blockage
  - Types and numbers of airborne nodes
  - Placement of airborne nodes – three dimensional diversity
  - Acquisition and tracking of airborne nodes

# Building Robust Links

- **Use high power transmitters**
- **Nearly all communication links operate with the transmitter beam larger than the receiver aperture ("Far field link")**
  - **Free space loss equal to the ratio of the illuminated area to the receiver aperture area**
- **Optical links may be operated in a far field link or a near field link**
  - **Near field link transmitter aperture just fills the receiver aperture thus minimizing the free space loss**
- **Near field link requires dynamic focusing and precise tracking**
  - **If the Fried coherence diameter is smaller than the aperture, then an adaptive optic system is required**
  - **Aircraft integration may preclude near field links**

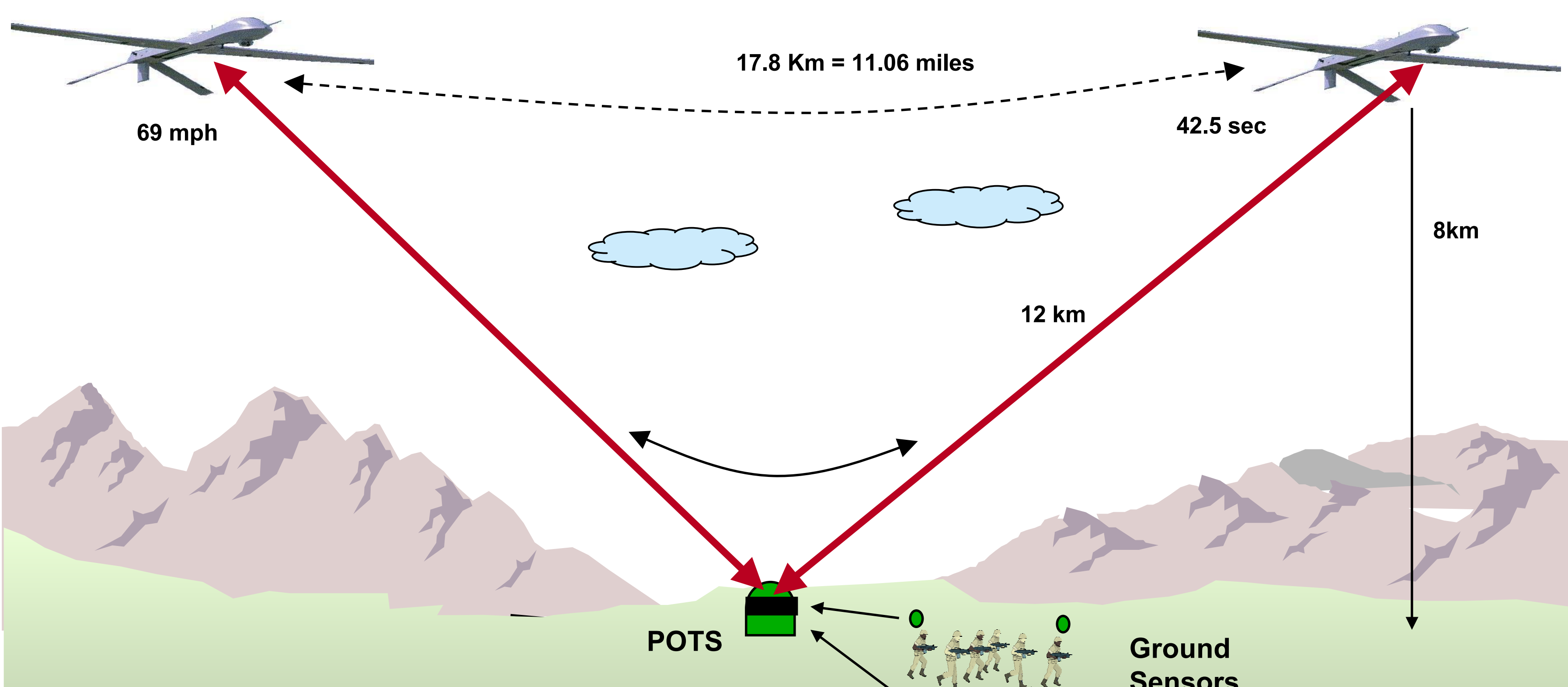
# Overcoming Atmospheric Turbulence

- If possible operate at elevation angles > than ~ 40 degrees
  - Minimizes both transmission losses and turbulence effects
- If sufficient link margin exists, build the transceiver terminal so that the aperture diameter is smaller than the Fried coherence diameter
  - Reasonable strategy for high altitude links
  - Reduces cost and complexity of the terminal
- Utilize interleaving and coding to build margin against turbulence fades
- Low altitude, horizontal paths may require adaptive optics to overcome the effects of turbulence
  - Consider a near field link to build a very robust link margin

# Overcoming Cloud, Fog and Terrain Blockages

- Broken clouds
  - Transmit THOR signals through openings in clouds
- Cloud layer
  - Build parallel links below and above cloud layer
  - Communicate between layers through an opening in the clouds
  - Fly under the clouds, "harvest" stored data and physically fly back up to restore network connection – POTS scenario
- Cloud undercast
  - Air vehicle towed passive optical terminals
    - Extend towed terminal below the undercast to communicate below and above cloud layer
  - Historic precedent in towed decoys, towed "cloud cars"
    - WW I - 1000 meter cables were used with cloud cars
- Fog and cloud overcast
  - Aerostat with fiber optic cable to optical terminal
    - Aerostat flies above cloud layer
  - Historic precedent in aerostat radars along southern border of the continental US
    - Now – 7600 m cables used with TARS radar aerostat
    - Aerostat hovers at 4600 meters

# Passive Optical Terminal Scenario – "Harvesting" Stored Data Files



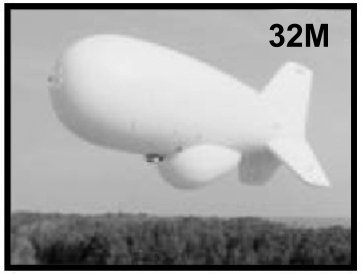

Loiter speed = 60 kts = 69 mph
Straight line travel time = (11.06 miles) (1Hr/69 miles) (3600 sec/hr) = 576 sec
Acoustic POTS data buffer = (10kHz BW) (2 samples/Hz) (16 bit A/D) (24 hrs) (3600 s/hr) = 34 Gbit
Time to transmit at 800 Mbps = (34 Gbit)(1sec/800Mbit) = 42.5 sec
Number of retransmits = 576 sec/ 42.5 sec = 13.5

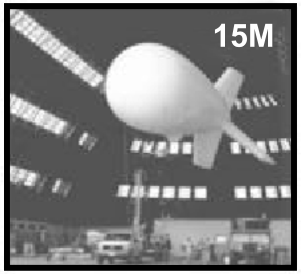
# Tethered Aerostat Radar System (TARS)

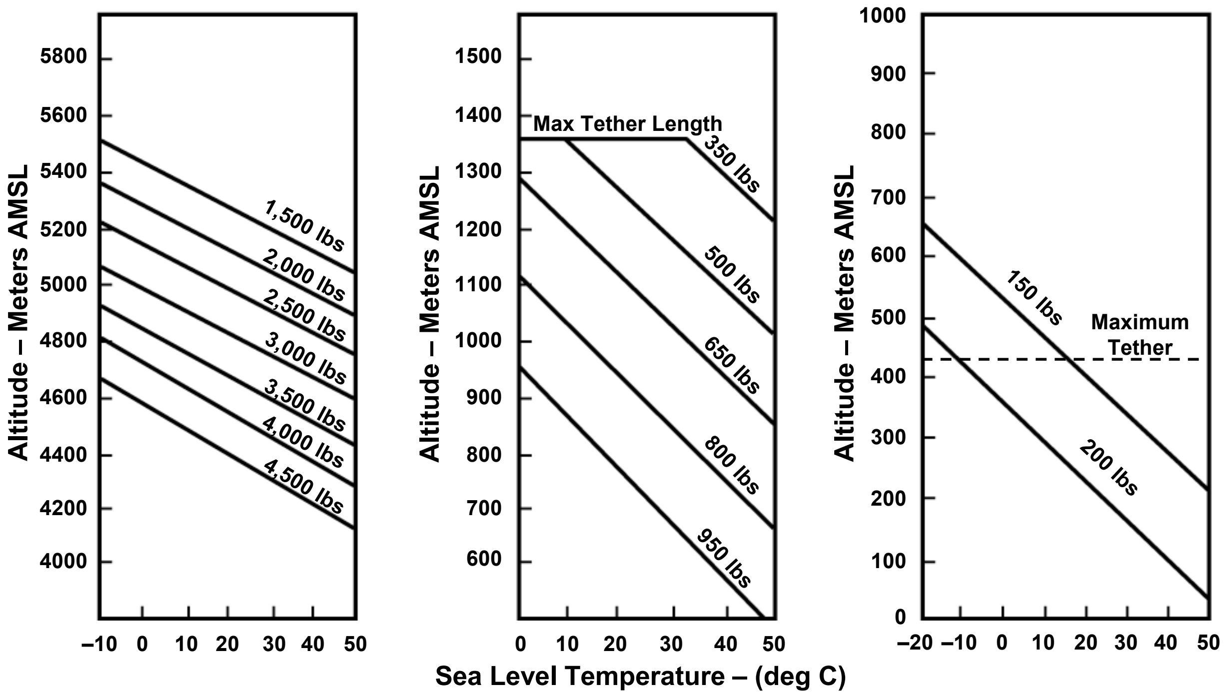
- Static radar site
- First deployed in 1984
- Two aerostat sizes
  - 275,000 cu ft – 32M aerostat
  - 420,000 cu ft – 71 M aerostat
- 8 sites
- Inventory – 12 + spares
- 10,000 to 15,000 foot operating altitude
- 1200 and 3400 lb payloads
- Stable in winds up to 65 knots
- Average Uptime ~ 60%, best site ~ 84%
- Cost per site - $ 2.8 M

71 M Aerostat

# TCOM Airship Specifications

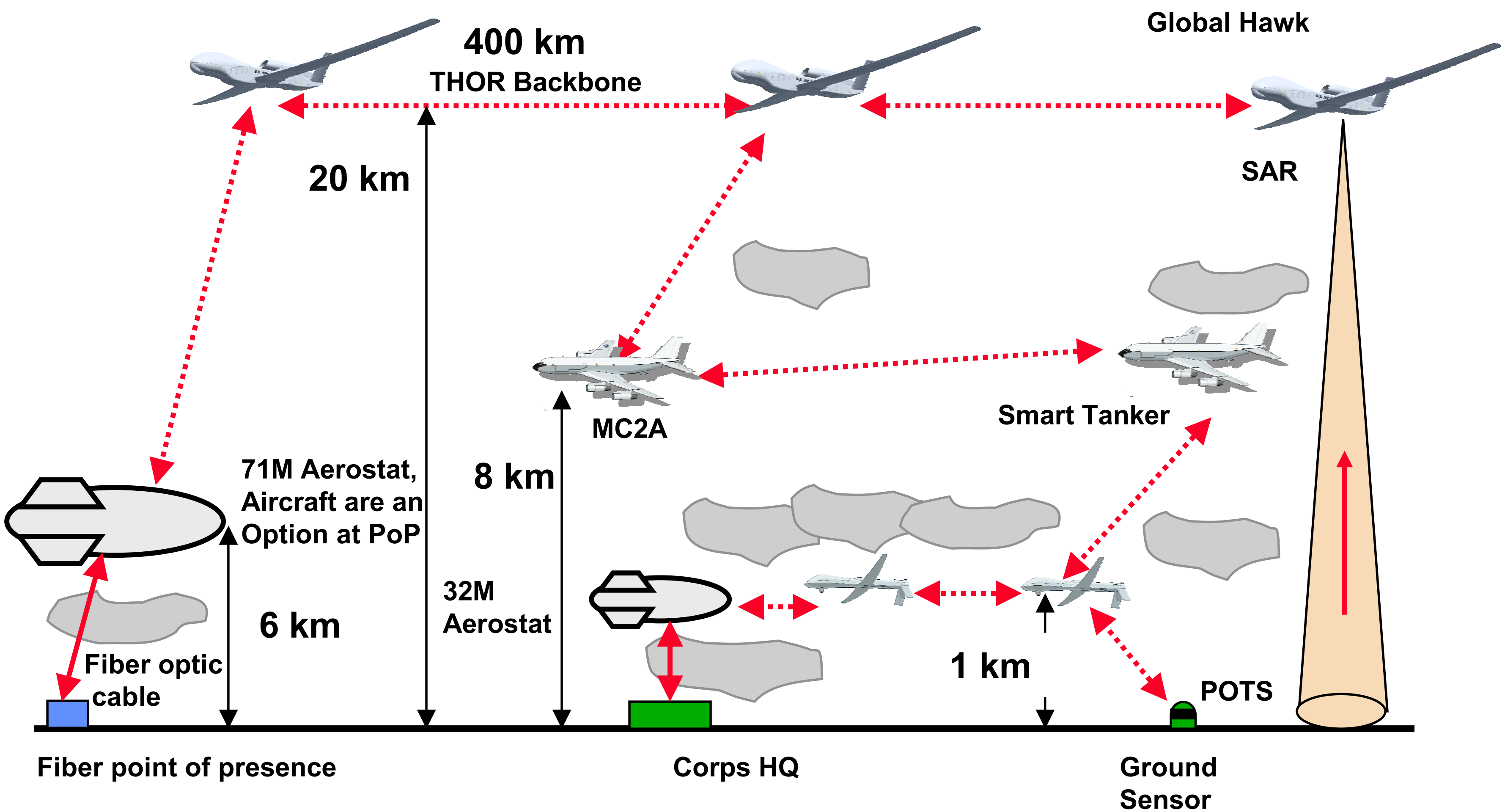




## 71M Aerostat
- Operational to 70 kts
- 30-day flight duration

## 32M Aerostat
- Operational to 50 kts
- 14-day flight duration

## 15M Aerostat
- Operational to 40 kts
- 5-day flight duration

# Link Geometries



# THOR Network Layer Issues - 1

- **Primary supported applications**
  - Streaming, high rate sensors
  - File transfer
  - "Instant messaging"
  - Web access
  - Email
  - Voice

- **Dynamic topology**
  - Nodes are deployed, move, go out of service
  - Dynamically establish and tear down links
  - Adjust to optimize service quality and resource utilization

# THOR Network Layer Issues - 2

- **Handover**
  - Level of transparency
    - Network level as in MobileIP (transparent to the application)
  - Sequencing
    - Make before break requires multiple ports
    - Buffering
  - Data handling
    - Lost data or long disconnects can impact throughput and latency
      - Buffer overflow or congestion control algorithms in the routers
      - TCP congestion control mechanisms
    - Avoid losing any data or permit higher layers of the stack to recover from losses

- **Quality of service (QoS)**
  - Latency
  - Throughput
  - Reliability

- **Security**
  - Denial of service – during acquisition
  - Compromise of a node
  - Authentication of handoffs, acquisition, etc.

# Summary

- THOR free space, mobile optical network potentially can bring broadband data into and out of the military theater of operations
- THOR has unique terminal concepts and platforms
  - Terminals should be modular, with the greatest variation seen in the free space optics subsystem
  - Passive optical terminal, in the form of a modulated retroreflector, can be used in a low cost store and forward application as well as an optical relay
- Primary network cost driver is associated with overcoming network blockages due to clouds