# 100 Gb/s RF Backbone (100G)

Proposers' Day Briefing

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# BAA Overview and Schedule

- BAA 13-15 – 100 Gb/s RF Backbone
- Announcements
  - BAA was posted to www.fbo.gov on January 3, 2013
- Schedule
  - BAA Released – January 3, 2013
  - Proposal Due Date (TA-1 and TA-2) – February 19, 2013
  - Abstract/Proposal Due Date (TA-3) – January 31, 2013 / March 21, 2013
- Administrative, technical or contractual questions should be sent via e-mail to DARPA-BAA-13-15@darpa.mil
- BAA-13-15 and associated amendments, will be the official documents for the proposals. They supersede statements made here.



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# PROGRAM OVERVIEW

100 Gb/s RF Backbone



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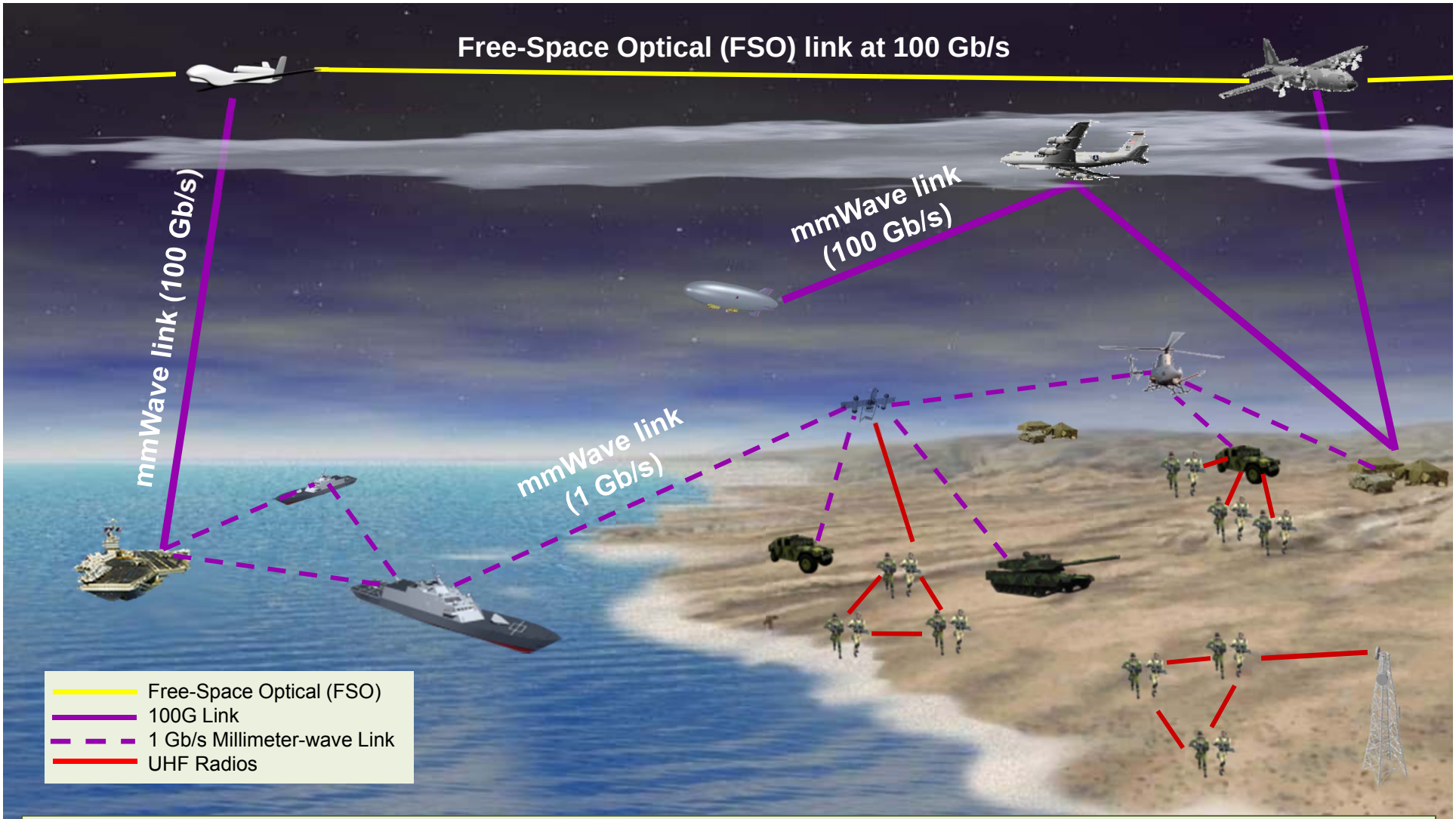
# 100G vision: fiber-optics-equivalent RF Backbone




Develop point-to-point link that uses high-order modulation and spatial multiplexing to achieve a high capacity (100Gb/s) RF backbone with tactically-relevant ranges

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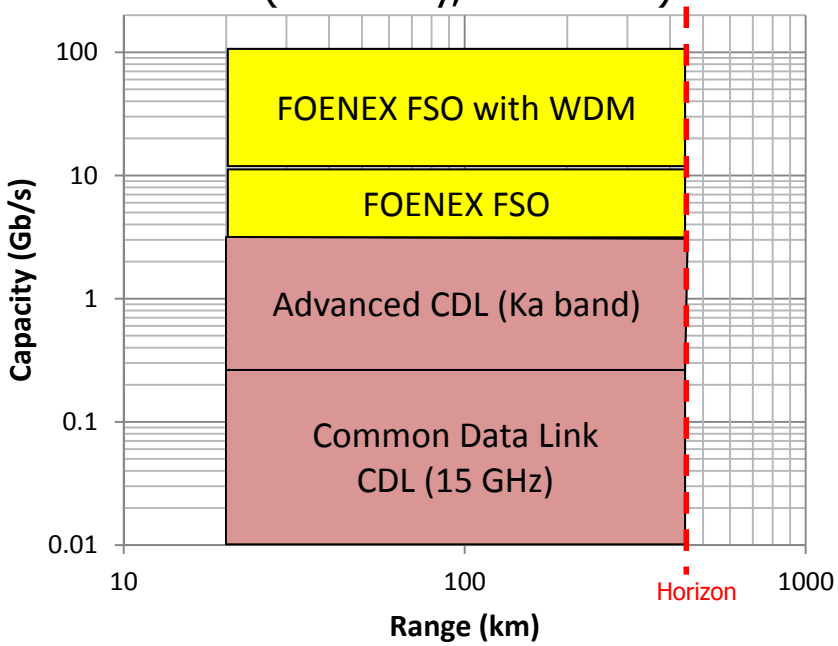
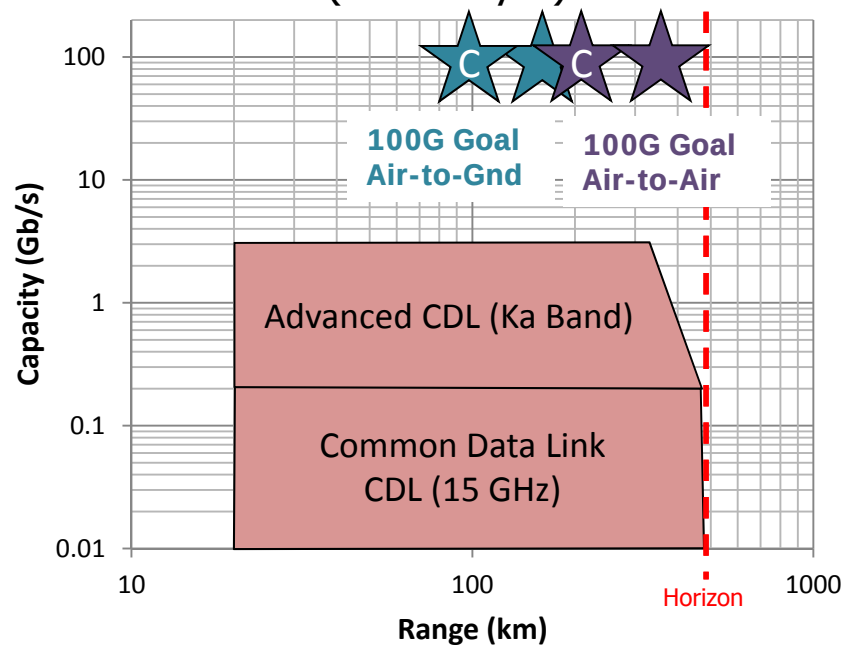
# Current State of the Art

Air-to-ground link from 60,000 feet
(Clear day, no clouds)




Air to ground link from 60,000 feet.
(Cloud layer)




Military communications must rely on a mobile infrastructure. Free-space optics provides the highest capacity at the farthest reach.

Free-space optical links will not propagate through the cloud layer. RF signals are the only option.

Providing fiber-optic-equivalent capacity on a radio frequency (RF) carrier will require spectrally efficient use of available RF spectrum



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# How do we increase capacity to 100 Gb/s?

$$\text{Capacity} = M \cdot B \cdot \underbrace{log_2\left(1 + \frac{S}{N}\right)}$$

Multiple channels

Bandwidth

Spectral efficiency
(Shannon's capacity theorem)

1. Increase bandwidth (move to higher frequencies):
   - Can lead to challenges with atmospheric losses

2. Apply spectrally efficient modulation (such as Quadrature Amplitude Modulation):
   - Requires a high signal-to-noise ratio (SNR) and thus a high transmit power and/or antenna gain

3. Use multiple independent channels (using spatial multiplexing):
   - Requires multiple apertures



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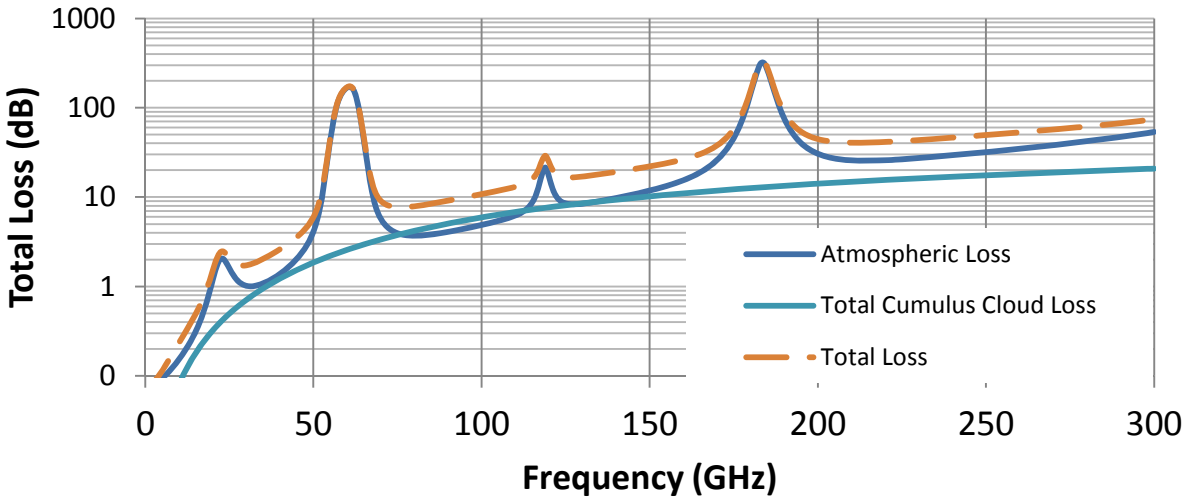
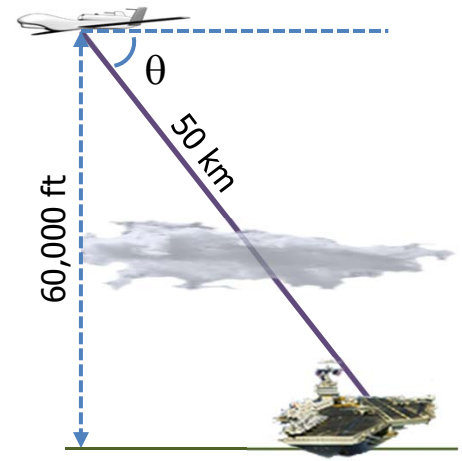
# Increasing bandwidth and signal-to-noise




Assumptions:
Air-to-ground link
Height: 60,000 feet
(18 km)
Tx Aperture: 12”
Rx Aperture: 12”



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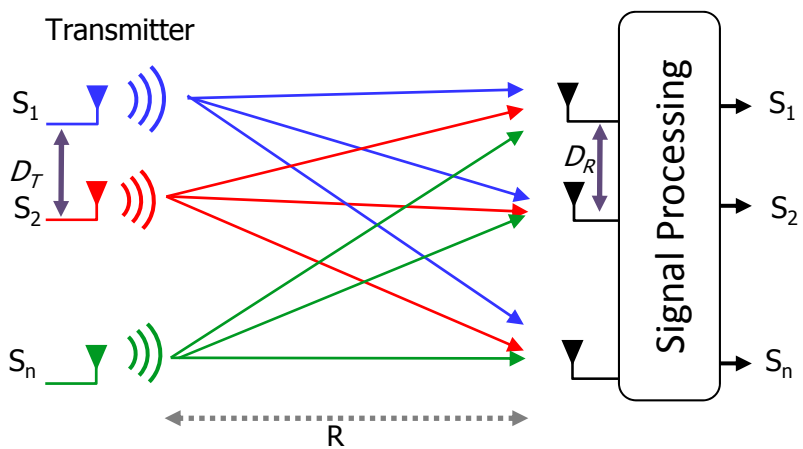
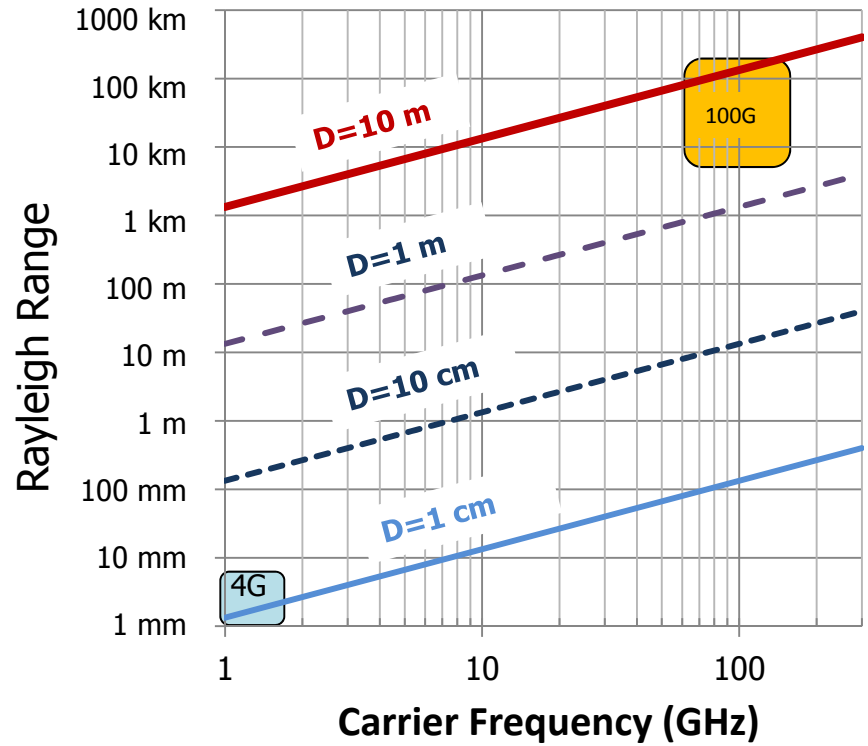
# Increasing M, the number of independent channels

- Use Spatial Multiplexing, operating at or near the Rayleigh Range, to form multiple, independent channels.
- Where the Rayleigh Range, R:

$$R \leq \frac{nD_T D_R}{\lambda}$$




**Insight:** Moving to millimeter-waves increases the Rayleigh Range and allows the formation of multiple independent channels.



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# BAA TECHNICAL DETAILS

Mobile Hotspots



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# BAA Overview

- Three technical areas:
  - Technical Area 1 – High Order Modulation at Millimeter-wave Frequencies
    - *TA-1 Option - High Order Modulation at Millimeter-wave Frequencies with Dual Polarization*
  - Technical Area 2 – Spatial Multiplexing at Millimeter-wave Frequencies (2x2)
    - *TA-2 Option – Spatial Multiplexing at Millimeter-wave Frequencies (3x3, 4x4)*
  - Technical Area 3 – Related Experimental Studies
- DARPA anticipates making *multiple* awards in each Technical Area (TA) in Phase 1.
- Proposers to this BAA may submit to any or all of the Technical Areas in Phase I but TA-3 will have a separate abstract/proposal process


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# Technical Area 1 Overview

- **TA-1 Base:** High Order Modulation at Millimeter-wave Frequencies
  - Develop and demonstrate methods for generating, transmitting, receiving, and processing high-order modulation at millimeter-wave frequencies
  - Develop and build a transmitter and receiver capable of transmitting data from a single transmit antenna to a single receive antenna at distances up to 10km
    - Spectral efficiency ≥ 5 bits/s/Hz and data rate ≥ 25 Gbps
    - No pointing, acquisition, and tracking required
  - BER will be measured with and without FEC and will be recorded as a function of receive power at several distances between 500 m and 10 km
  - Performer will experimentally determine ADC requirements for the receiver including bandwidth, ENOB, phase noise, jitter
- **TA-1 Option:** Demonstrate high-order modulation on two polarizations to achieve a total data rate of 50 Gbps from a single transmit antenna to a single receive antenna

It is anticipated that the TA-1 Base and Option efforts will be awarded concurrently.
It is anticipated that the TA-1 Base and Option efforts will be conducted concurrently.


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# Elements of the program – Phase 1: TA-1

- **TA-1 Base: High Order Modulation**
  - Demonstrate the ability to modulate and detect high-order modulation on a mmWave carrier
    - Experimentally determine A/D requirements (SNR, conversion time, ENOB and jitter)

| Parameter | Metric |
|---|---|
| Symbol Rate | > 4 G symbol/sec |
| Output mmWave Power | > 100 mW |
| Spectral Efficiency by High-Order Modulation | ≥ 5 (b/s)/Hz |
| Data Rate | 25 Gb/s |
| Measurement Distance | > 10 km |

- **TA-1 Option**
  - Demonstrate the ability to modulate and detect high-order modulation on a mmWave carrier on two polarizations

| Parameter | Metric |
|---|---|
| Symbol Rate | > 4 G symbol/sec |
| Output mmWave Power | > 100 mW |
| Spectral Efficiency by High-Order Modulation | ≥ 5 (b/s)/Hz per polarization |
| Data Rate | 50 Gb/s |
| Measurement Distance | > 10 km |

TA-1 will experimentally demonstrate how high-order modulation formats can be used to increase spectral efficiency.



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# Technical Area 2 Overview

- **TA-2 Base**: Spatial Multiplexing at Millimeter-wave Frequencies
  - Develop and demonstrate a multi-aperture (2x2) millimeter-wave link to validate the Rayleigh range as a function of antenna spacing and to demonstrate line-of-sight spatial multiplexing
  - Performer will create a link with two transmit and two receive antennas to demonstrate data rates ≥ 4 Gbps using spatial and polarization multiplexing
    - No high-order modulation will be used
    - Independent streams will be ≥ 1 Gbps
  - Performers will experimentally determine the capacity as a function of range and antenna separation
    - Field testing beyond 50 km will be required
  - Performers should simulate the impact of doppler on the processing requirements for aircraft travelling between 50 m/s and 250 m/s
- **TA-2 Option**: Experimentally evaluate the line-of-sight spatial multiplexed link with three transmit and three receive antennas (3x3) as well as four transmit and four receive antennas (4x4)



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# Elements of the program – Phase 1: TA-2

- **TA-2 Base: mmWave Spatial Multiplexing**
  - Experimentally validate the line-of-sight spatial multiplexed link with two transmit and two receive antennas (2x2).

| Parameter | Metric |
|---|---|
| Number of Antennas | 2x2 |
| Number of Independent Channels | 4 |
| Bit Rate | ≥ 1 G b/sec |
| Peak Bit Rate | ≥ 4 G b/sec |
| Output Power | ≥ 100 mW |
| Measurement Distance | > 50 km |
| Antenna Spacing | 0.1 meters to 10 meters |

- **TA-2 Option:**
  - Experimentally evaluate the line-of-sight spatial multiplexed link with three transmit and three receive (3x3) antennas and four transmit and four receive (4x4) antennas.

| Parameter | Metric |
|---|---|
| Number of Antennas | 3x3, 4x4 |
| Number of Independent Channels | 6, 8 |
| Bit Rate per Channel | ≥ 1 G b/sec |
| Peak Bit Rate | ≥ 8 G b/sec |
| Output Power | ≥ 100 mW |
| Measurement Distance | > 50 km |
| Antenna Spacing | 0.1 meters to 10 meters |

TA-2 will experimentally demonstrate spatial multiplexing technologies can be used to increase spectral efficiency.
It is anticipated that the TA-2 Base and Option efforts will be awarded concurrently.
It is anticipated that the TA-2 Base and Option efforts will be conducted concurrently.


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# Technical Area 3 Overview

- TA-3 will consist of feasibility studies that provide proof-of-concept demonstrations and trade studies key to the operation of the 100G system
- Abstracts for TA-3 are strongly encouraged prior to submission of a proposal
- TA-3 will have a different timeline than the other TAs

- **Specific topics of interests include, but are not limited to, the following:**
  - Efficient Power Amplification at Millimeter-wave Frequencies
  - Conformal Antennas at Millimeter-wave Frequencies
  - Multifunction Millimeter-wave Trade Study
  - 100G Networking Trade Study
  - 100G Waveform Development
  - Efficient Signal Processing
  - Other Topics of Interest


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# Phase 2 Overview

- **Phase 2: Prototype Development**
  - Build a prototype point-to-point communications link with pointing, acquisition, and tracking

| Parameter | Metric |
|---|---|
| Downlink Information Rate | 100 Gb/s |
| Uplink Information Rate | 10 Gb/s |
| BER | $\leq 10^{-8}$ |
| Measurement Distance | > 50 km |
| Mountain to GND tests | Clear > 100 km<br>Clouds > 50 km |
| Size | TBD |
| Weight of Transceiver | < 200 lbs |
| DC Power Consumption of Transceiver | < 1000 Watts |

- Prototype development, integration, and initial field testing
- One prototype system will be developed and will include pointing, acquisition, and tracking capabilities
  - Each system will comprise two millimeter-wave transceivers with asymmetric link performance: 100 Gbps downlink and 10 Gbps uplink
- Field tests will be conducted in mountain-to-ground configurations
- Multiple configurations will be tested to characterize system performance and ability to meet program capacity, distance, availability, and SWaP goals

During Phase 2, the performers will build a prototype system with the size, weight and power consistent with the high altitude, extended persistence platforms being considered for deployment



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# Phase 3 Overview

- **Phase 3: System Flight Test**
  - Integrated into a test aircraft
  - Air-to-Ground tests to 100 km

| Parameter | Metric |
|---|---|
| Data Rate (w/BER = $10^{-6}$) | 100 Gb/s |
| Air-to-Ground Range Goal (at 15,000 ft) | ≥ 50 km |
| Air-to-Air Range Goal (at 15,000 ft) | > 100 km |
| Doppler | TBD |
| Aircraft Velocity | ≥ 50 m/s |

- Phase III will focus on prototype development and flight testing
- The system will be integrated into air and ground platforms for air-to-air and air-to-ground testing
  - Two series of air-to-air and air-to-ground flight tests will occur
- As in Phase II, multiple configurations will be tested (subject to aperture integration constraints on the aircraft)

During Phase 3, performers will integrate the system into multiple configurations of air and ground platforms to perform two test cycles or air-to-air and air-to-ground flight tests.



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# BAA PROGRAMMATIC DETAILS

100G



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# Funding

- $18,300,000 to be awarded to multiple performers in Phase I
  - Multiple awards are anticipated for each of the three technical areas
  - TA-1, 2, and 3 will run concurrently; TA-1 and TA-2 will be 20 month efforts and TA-3 will be up to an 18 month effort
- Estimates for total budget and duration for each technical area are shown below:

| Technical Area | Number of Awards | Total Budget | Duration |
|---|---|---|---|
| TA-1 — High-Order Modulation at Millimeter-wave Frequencies | Multiple | ~35-45% | 20 months |
| TA-2 — Spatial Multiplexing at Millimeter-wave Frequencies | Multiple | ~35-45% | 20 months |
| TA-3 — Related Experimental Studies | Multiple | ~10-15% | < 18 months |
| | | $18,300,000 | 20 months |



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# Notional Schedule Overview

| | FY13 | FY14 | FY15 | FY16 | FY17 |
|---|---|---|---|---|---|
| **Phase 1: System Design** | | | | | |
| • TA-1 mmWave High-Order Modulation | Multiple Performers | | | | |
| • TA-2 mmWave Spatial Multiplexing | Multiple Performers | | | | |
| • TA-3 Related Experimental Studies | Multiple Performers | | | | |
| **Phase 2: Prototype Integration**<br>• Prototype Build<br>• Pointing, Acquisition and Tracking<br>• Mountain-to-Ground Demonstration | | | 1 or 2 Performers | | |
| **Phase 3: System Demonstration**<br>• Technical Upgrade<br>• Integration onto Platform<br>• Two Flight Tests (Test-fix-test) | | | | | 1 or 2 Performers |



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# Evaluation Criteria

- Proposals are evaluated on the following criteria:
  - Overall Scientific and Technical Merit
  - Potential Contribution and Relevance to the DARPA Mission
  - Realism of Proposed Schedule
  - Proposer's Capabilities and/or Related Experience
  - Plans and Capability to Accomplish Technology Transition
  - Cost Realism



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# Organization Name Schedule/Cost

| Cost Element | TA Base | TA Option | Comments |
|---|---|---|---|
| Contract Type | | | |
| Number of Months | | | |
| Prime Labor | $ | $ | Direct Labor + Benefits + Overhead |
| Prime Labor Hours | | | |
| Prime ODC's | | | |
| Prime Materials | $ | $ | Detail list w/cost |
| Prime Travel | $ | $ | |
| G&A | $ | $ | G&A _% |
| Subcontractor – | $ | $ | Contract type / effort |
| Subcontractor – | $ | $ | Contract type / effort |
| Other | $ | $ | |
| Program Total (w/Fee) | $ | $ | |



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