# Advanced Radio Frequency Mapping (RadioMap) Proposer's Day Briefing

Dr. John Chapin

March 14, 2012



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# BAA Overview and Schedule

BAA 12-26 – Advanced RF Mapping (RadioMap)

Announcements

BAA was posted to www.fbo.gov on February 29, 2012

Schedule

BAA Released – February 29, 2012

Proposal Due Date – April 16, 2012

Administrative, technical, or contractual questions should be sent via email to

DARPA-BAA-12-26@darpa.mil

BAA-12-26 and associated amendments, will be the official documents for this solicitation. They supersede statements made here.

# Outline

**Overview**

Task 1 and TA1: RF Situational Awareness

Task 2 and TA2: WALDO system

Task 3 and TA3: Other Capabilities

Task 4: RF Device Sharing Techniques

Anticipated Phase 3


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# RadioMap program drivers

## Challenge

Increasing complexity and density of RF spectrum usage.  Challenge for 3 DOD communities:

Spectrum managers / Dynamic Spectrum Access communications systems

- lack real-time information needed for efficient spectrum allocation

Small-unit tactical leaders

- lack RF situational awareness of threats and opportunities nearby

Electronic Warfare officers

- coverage is sometimes limited by high cost of current EW devices and platforms

## Opportunity

Increasingly flexible and powerful mobile devices

Increasing tuning range of tactical radios, including handhelds


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# RadioMap program vision

RF devices support RF situational awareness and other EW/ISR functions in addition to and without harm to their primary mission.

- RF devices include communications devices, radars, sensors, …
- "Without harm" is determined by commander controlling the device

General benefits

- Capability: Enable new EW/ISR functions that employ a large network of receivers and transmitters
- Acquisition: Reduce the cost and delay of deploying new EW/ISR functions
- Availability: Make EW/ISR functions more widely available on the battlefield


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# RadioMap program goals

Develop RF situational awareness technology (AKA "RF Mapping")

- Observe transmissions (assess radio frequency usage)
- Determine the type and characteristics of active devices and networks
- Estimate spectrum occupancy and usage throughout the area of interest

Provide RF Mapping support for three end user communities

- Each has unique data access, user interface, control mechanism requirements

1. Spectrum managers and DSA systems
2. Small-unit leaders
3. Electronic Warfare Officers and systems

Study other capabilities that employ the network of receivers and transmitters

(anticipated) Demonstrate at least 2 other capabilities


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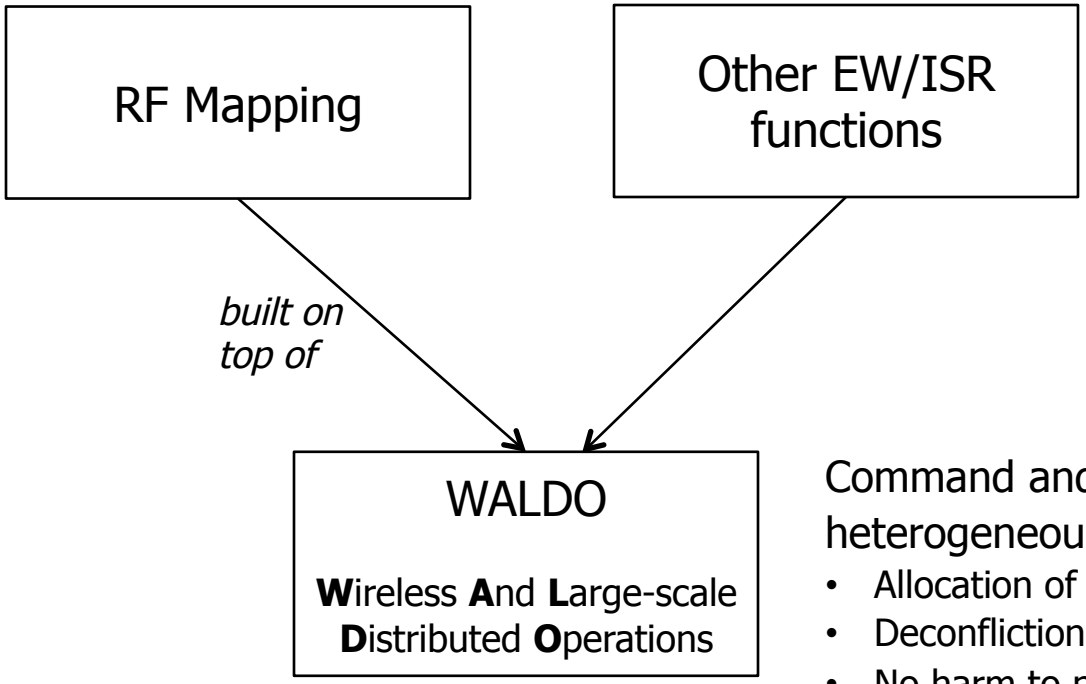
# RadioMap implementation strategy




"Applications"

Command and control of a large network of heterogeneous RF devices

- Allocation of tasks to devices
- Deconfliction between tasks
- No harm to primary missions of the devices

*WALDO solves the common problems faced by any EW/ISR function that seeks to exploit RF devices deployed for other missions.*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# RadioMap Technical Areas

Technical Area One (TA1) RF Situational Awareness

RF mapping technology and capabilities

Technical Area Two (TA2) WALDO System

Command and control of a large network of heterogeneous RF devices

Technical Area Three (TA3) Other Capabilities

EW/ISR or other functions that exploit the RF receivers and transmitters available in theater


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# RadioMap program phases

Three program phases are anticipated.

| **Phase 1**<br>**Technology Development, Demonstrations and Studies** | **Phase 2**<br>**Further Technology Development, Field Trial** | **Phase 3**<br>**System Integration and Field Trials** |
|---|---|---|
| Task 1: RF Mapping approaches<br>*Supports Technical Area One* | Task 1: RF Mapping approaches<br>*Supports Technical Area One* | Tasks not yet specified |
| Task 2: WALDO system architecture<br>*Supports Technical Area Two* | | |
| Task 3: Capability studies<br>*Supports Technical Area Three* | | |
| Task 4: RF Device sharing techniques<br>*Supports Technical Areas One and Two* | | |
| Approx. 12 months | Approx. 12 months | Approx. 24 months |

**A performer may propose work for any or all tasks.**
**A separate proposal should be submitted for each task.**
**Phase 1 Task 1 proposals should provide a priced option for Phase 2 Task 1.**
**No proposals for Phase 3 work are being solicited at this time.**


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# RF mapping defined

The map should give the following information:

If a receiver were located at some location (X,Y) what signals would it observe?

- For each frequency band or channel F
- Over each time period T

(X, Y, F, T) ➔ { $Group_1$, $Group_2$, … }

where

Group reports emissions by a group of like emitters sharing the channel

= (center frequency, bandwidth, peak aggregate power over period T, % occupancy over T)

The map should also indicate System Type

$Group_n$ ➔ S

S = English descriptor that indicates the signal externals and behavior of a system.

Examples include "3G cellular" and "FM push-to-talk."


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# RF mapping anti-defined

RF mapping ≠ geolocation of emitters

- It's a map of what a receiver would hear based on its location, not a map of the locations of transmitters.

RF mapping ≠ monitoring of communications

- The map tells you the signal type and the system type, not the data content


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# RF mapping challenges

Urban area

- High multipath, fading, shadowing
- Moderate mobility

Dense RF signal environment

- Potentially 1000s of emitters per square kilometer
- Many are low-power / short range

Limited receiver resources – cannot assess all locations and frequencies all the time

- Must sample and interpolate/extrapolate in both space and time
- Exploit information such as:
    - Models of emitters and networks
    - Maps of the urban environment and terrain
    - Propagation models
    - Spectrum license databases

Many or most receivers are not controlled by the RF mapping algorithm


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# RF mapping metrics and goals

| Metric | Phase 1 Goal | Phase 2 Goal |
|---|---|---|
| **Coverage** | | |
| Frequency range | 470-928 MHz | Same |
| Signal bandwidth | 20 kHz-10 MHz | Same |
| Power level | (*) | Same |
| Area (dense urban area, chosen by performer) | 4 $mi^2$ | 9 $mi^2$ |
| Sensor count | <= 25 RF devices | <= 75 RF devices |
| **Spectral Mapping**<br>Build a map showing X% of target signal groups. | 50% | 75% |
| **System Assessment**<br>Label what system type generated each signal group for X% of entries in the map. | 50% | 65% |
| **Anomaly Detection**<br>Discover and report X% of anomalous transmissions within Y minutes. | Not required | X=75%<br>Y=5 minutes<br>False alarms < 3/hour |

(*) power > 4.7dB SNR at a legally accessible location > 70m from emitter

Mapping thresholds:

| | |
|---|---|
| Spatial resolution | 200m |
| Time resolution | 10s |
| Accuracy | 90% |

Additional goal:
Minimize cost required for demonstrated level of performance


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# Phase 1 vs Phase 2 operating environment

Phase 1

Software need not run on top of a WALDO system

RF devices need not be shared with other functions

RF devices need not be heterogeneous

RF devices may be static or mobile

Server and network resources unlimited

Phase 2

Software need not run on top of a WALDO system

RF devices need not be shared with other functions

- However, techniques that maximize mission utility given varying RF device availability should be demonstrated and evaluated

Use of heterogeneous RF devices is encouraged

At least 15% of RF devices must be mobile

Server resources unlimited

Network connection to each RF device limited to 300 kilobits/second

- Techniques that maximize mission utility given varying communications availability should be demonstrated and evaluated


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Anticipated Phase 3


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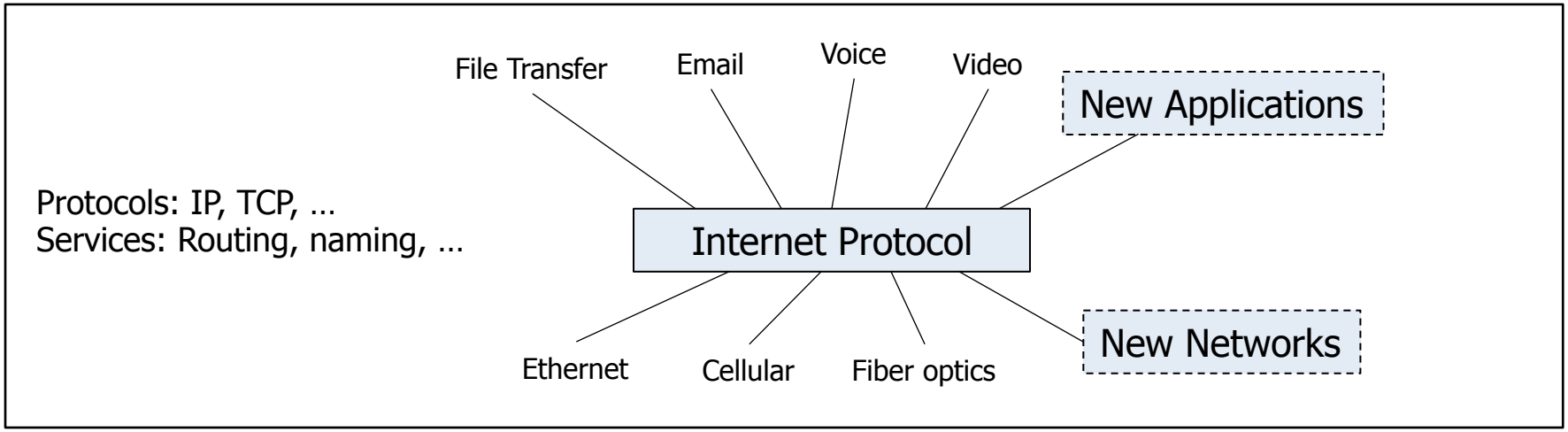
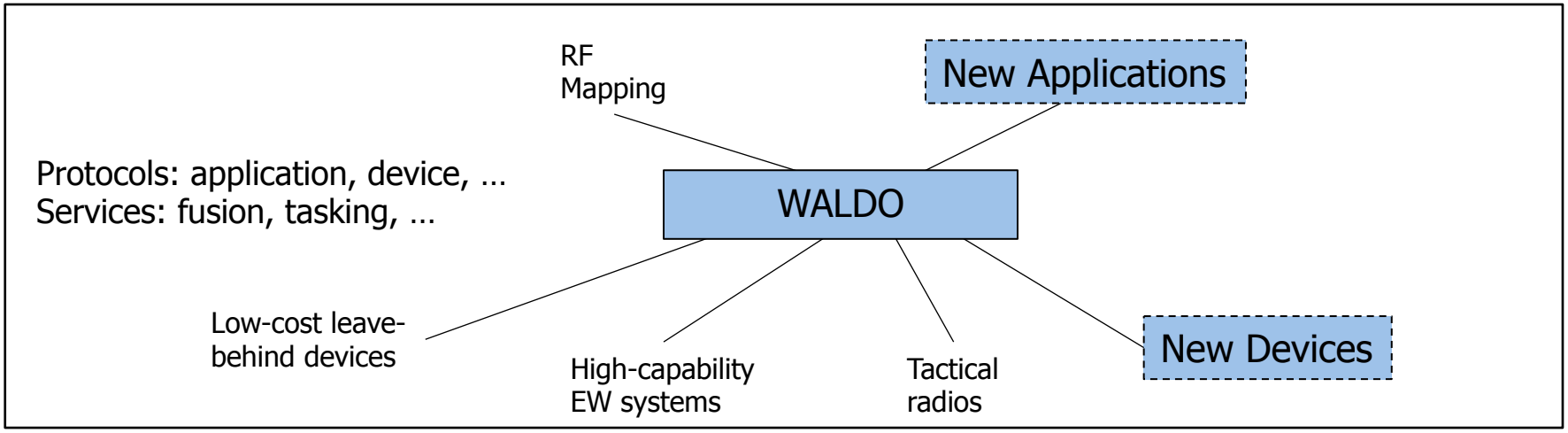
# WALDO: The "narrow waist" for networked RF functions




IP enables any application to exploit any available network.
WALDO enables similar modularity for networked RF functions.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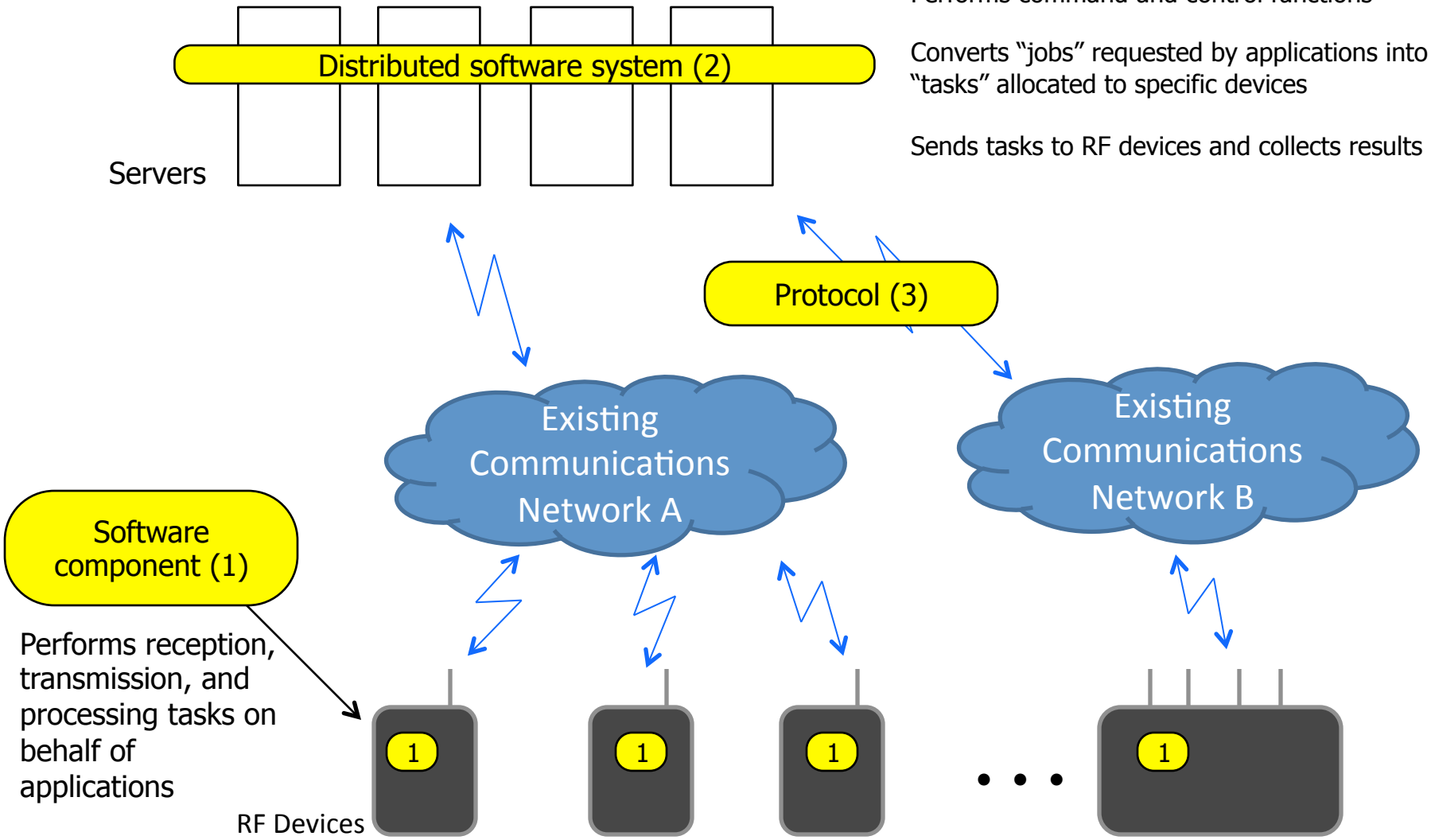
# WALDO components (notional)




Performs command and control functions

Converts "jobs" requested by applications into "tasks" allocated to specific devices

Sends tasks to RF devices and collects results



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# WALDO challenges (1 of 3)

Any RF device can perform tasks for any application,

without specializing software component (1) on the RF device for the application,

Software on the device faces conflicting goals. It should be:

Flexible – to support a range of applications without software change

Efficient – to perform local processing on behalf of applications with minimal delay or resource use

Capable of exploiting specialized processing resources

- E.g. field-programmable gate arrays, DSPs, graphics processors

without specializing the application implementation for the device,

How to appropriately abstract the details of device variations

and without specializing the system (2) or protocol (3) for either the device or the application

How to convert jobs into tasks in a way that works for a range of applications and devices

How to design a protocol that is both efficient and general


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# WALDO challenges (2 of 3)

| Feature from BAA | Example challenges |
|---|---|
| Robust operation | Don't crash the RF devices.<br>Survive application misbehavior. |
| Secure operation | Don't create a new vector for adversaries to hack into the RF devices. |
| Efficient operation | Minimize consumption of device and network resources to carry out requested jobs. |
| Support multiple simultaneous applications | Automatically prevent fratricide. |
| Scalable to 1000 or more RF devices | Quick conversion from jobs to tasks at large scales. |
| When network quality of service is low | Tolerate high jitter and high packet loss. |
| When information about the RF devices and the environment is uncertain | Achieve efficient operation despite poor device location information, rapid changes between available and busy status. |


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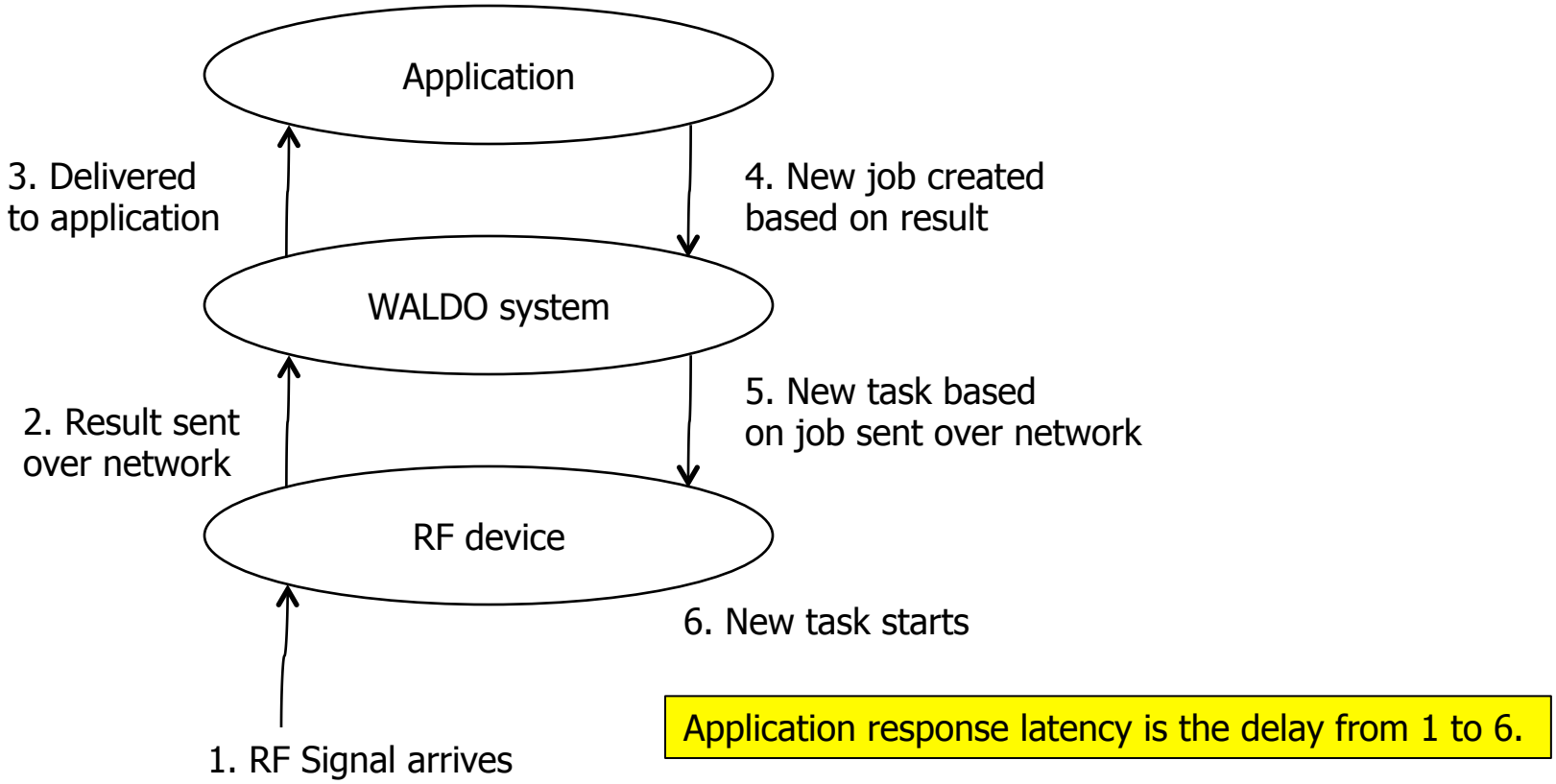
# WALDO challenges (3 of 3)

Minimize application response latency and its growth with increasing system size and utilization.




*Minimizing application response latency requires careful attention to efficiency and distributed operation in all aspects of the system architecture and implementation.*

# Additional evaluation criteria for Task 2 proposals

Proposer's Capabilities and/or Related Experience

For proposals to investigate WALDO system design (Task 2), demonstrated experience to develop systems in three areas is equally important:

(1) systems that achieve effects goals efficiently in complex uncertain environments,

(2) systems or interfaces that act as the common element enabling a diversity of applications to exploit a diversity of hardware devices, and

(3) scalable resource-constrained distributed systems.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# Other Capability Studies

Capabilities of interest

- Capabilities are sought that offer high utility justifying the cost per square kilometer covered, with the appropriate utility and cost metrics to be defined for the capability by the proposer.

Open to capabilities of any type

Should leverage the network of available receivers and transmitters

May be located in ground, airborne, or other locations

Can combine the network with other devices to achieve new capability

Outputs of the study

Requirements on underlying devices and communications network

Requirements on WALDO system

Utility and cost metrics and predicted capabilities


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# Additional evaluation criteria for Task 3 proposals

For proposals to investigate other capabilities (Task 3), other factors to be considered include the following.

Overall Scientific and Technical Merit

- The capability if demonstrated in Phase 3 will exploit the underlying WALDO system in a sufficiently different fashion from RF situational awareness that carrying out the demonstration will help stimulate and validate the ability of the delivered WALDO system to support a wide range of EW/ISR applications.

Potential Contribution and Relevance to the DARPA Mission

- The capability exploits the heterogeneous set of sensors and transmitters provided by WALDO to deliver military benefits that are of high and immediate utility in current or near-future operations and that cannot be achieved affordably using current approaches.


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# Operation without harm to the primary mission of the RF device

Given a radio that runs a data network waveform, add signal search functionality

- Across a frequency range larger than instantaneous bandwidth of the receiver

Execute both networking (transmit and receive) and signal search simultaneously, with limited or no impact on the networking function.

Quantify increasing impact on communications metrics as search workload increases

Particularly interesting:

- Data networks where timing of incoming transmissions is not fully predictable
- RF devices representative of a current or near-future tactical radio
- Implementation strategies that minimize modifications to low-level firmware
- (For multichannel devices) Configurations where the channel used for search is sometimes needed for communications


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**Anticipated Phase 3**


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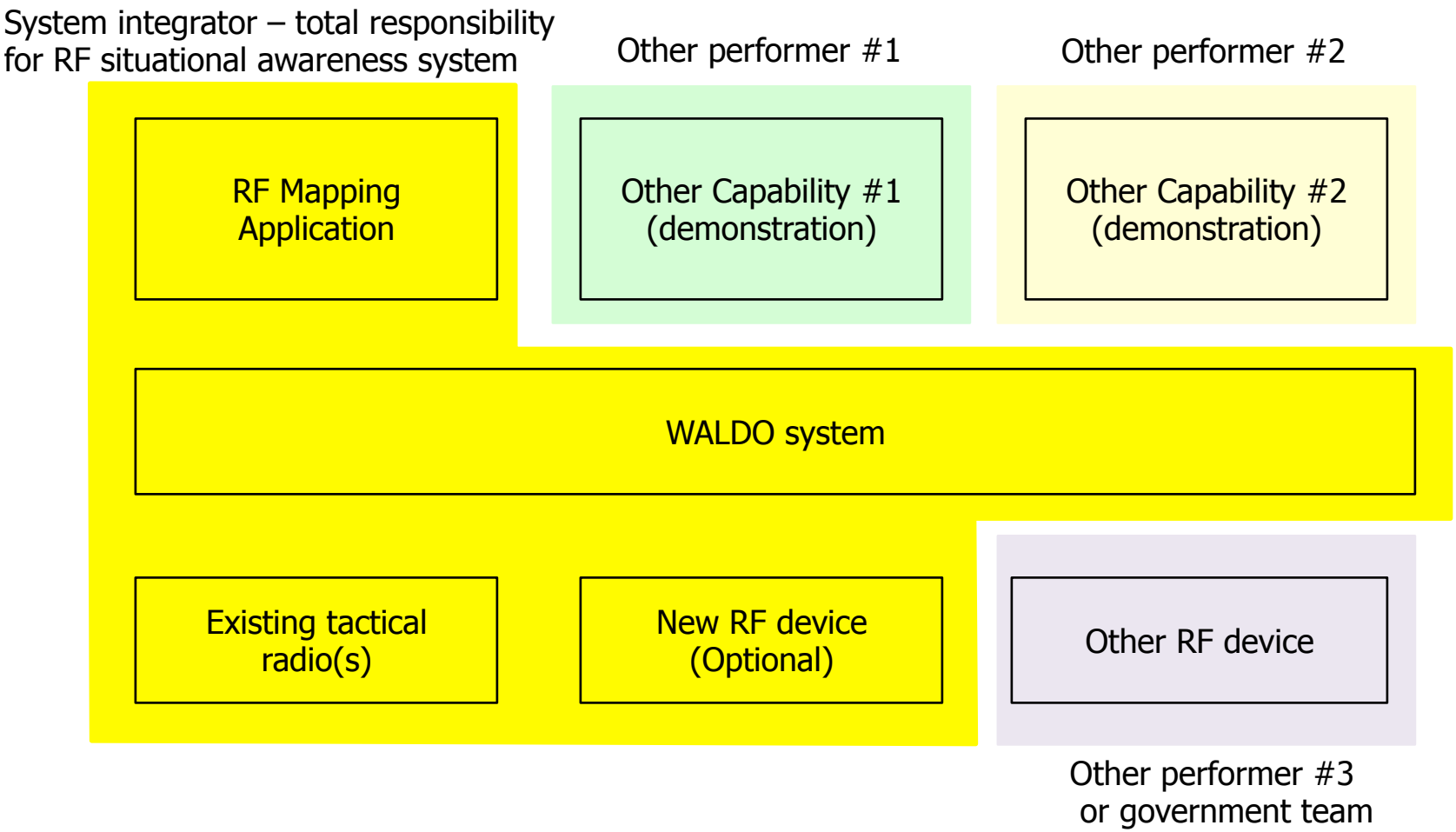
# Phase 3 performers (anticipated)




Other performers are independent from system integrator to promote openness of WALDO
Other Capabilities are different from RF mapping to promote flexibility of WALDO
Other RF device is different from system integrator's devices to promote flexibility of WALDO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# Ensuring Phase 3 system and devices support the applications

- Non-proprietary outputs from Phase 1 Task 1 (RF mapping) and Task 3 (Other Capabilities)
  - Features and key performance metrics needed in the WALDO system
  - Features and key performance metrics needed in the RF devices and communications network
- These may be used by the government in the solicitation for the Phase 3 system integrator

- Non-proprietary output from Phase 1 Task 2
  - WALDO system document
  - Documentation for other organizations building applications or connecting new devices to the WALDO system
- This may be used by the government in solicitations for Phase 3 application developers
- (Anticipated) Document will be revised during Phase 3 as system develops


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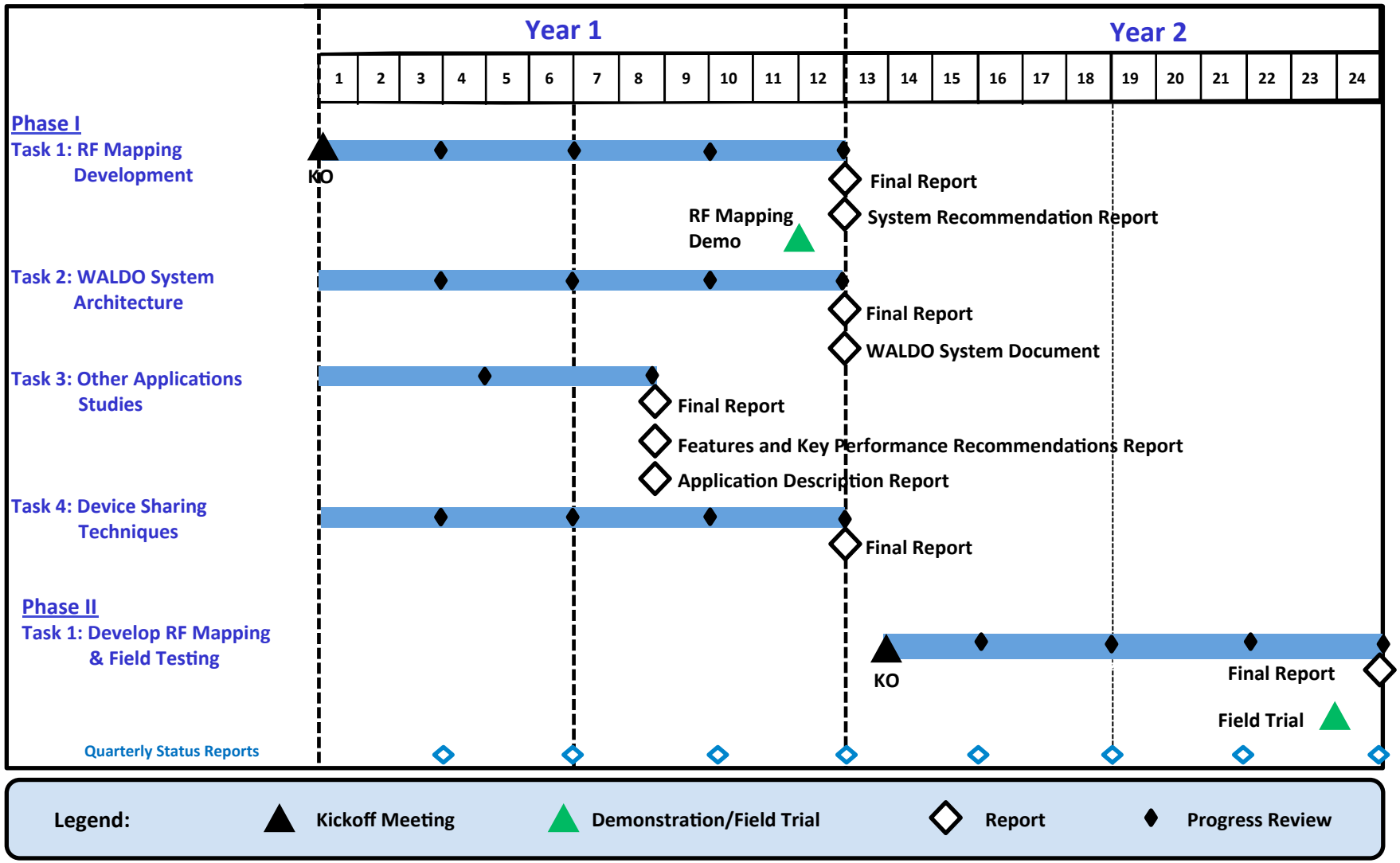
# Program Schedule




Phase 3 is anticipated to start before the end of Phase 2 and continue for roughly 2 years

# Alternative Techniques: Use of Urban Propagation Characteristics

P Kolodzy, PhD
DARPA Consultant/SETA

Disclaimer: "The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government."

Industry Day

14 March 2012

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The measurements presented here are taken completely from measurements published by Johns Hopkins University Applied, Applied Physics Laboratory in IEEE (Hampton, Merheb, Lain, et al)

Hampton, J.R.; Merheb, N.M.; Lain, W.L.; Paunil, D.E.; Shuford, R.M.; Kasch, W.T.; , "Urban propagation measurements for ground based communication in the military UHF band," Antennas and Propagation, IEEE Transactions on , vol.54, no.2, pp. 644- 654, Feb. 2006

# Preamble

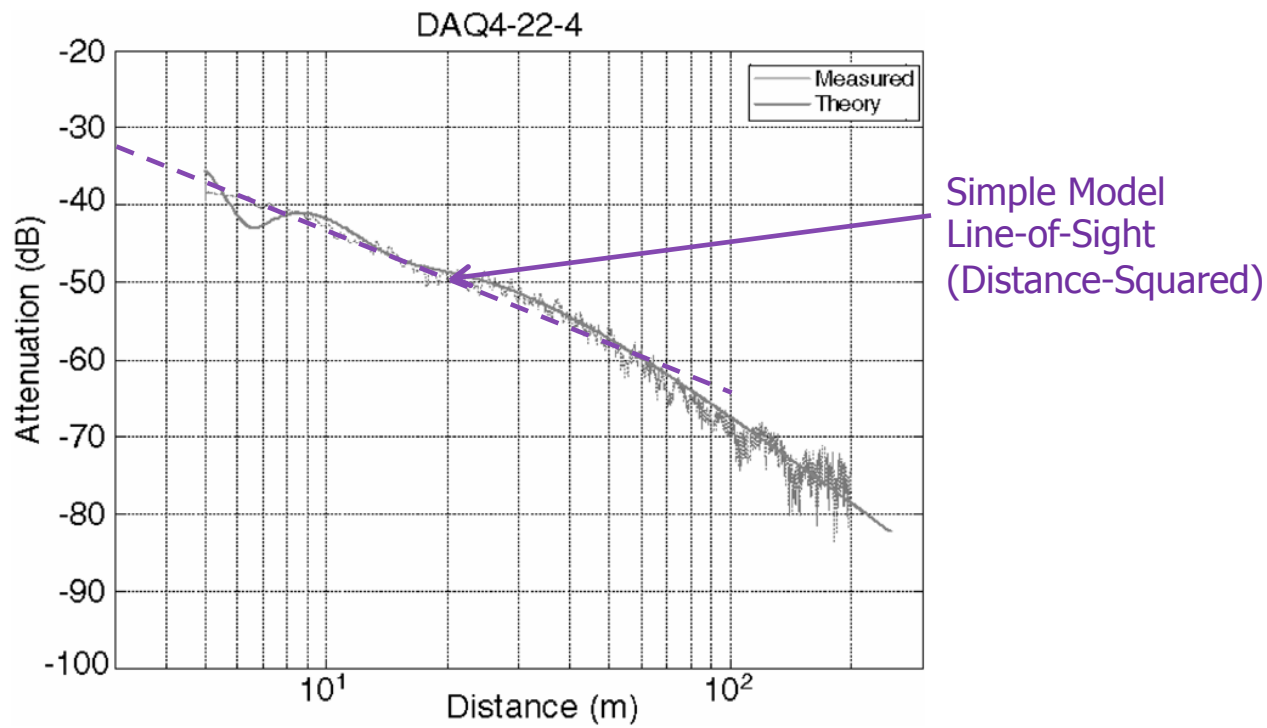
# Baghdad Example

# Propagation Measurements in Urban Corridor

- Investigate dependencies on transmission frequency and street width
- Investigate the impact of corner (turn)
- Investigate the impact of distance from transmitter (receiver) from turn

# Line-of-Sight Propagation Models

(2.3 meter height above ground → 2.3 meter height above ground )




Two-Ray Model, Line-of-Sight, 350 MHz

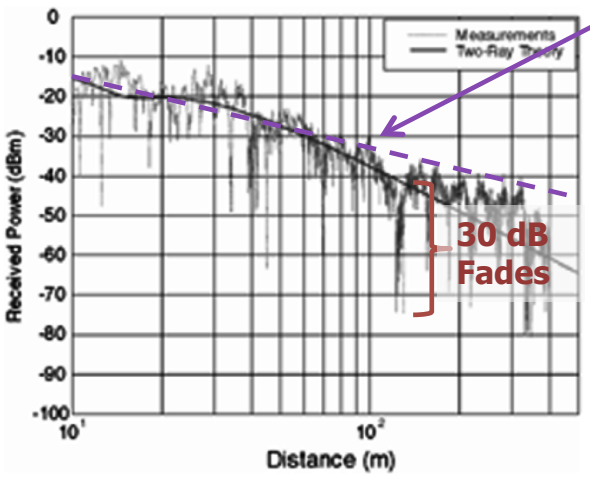
- Cellular models are Low-Site → High-Site, recent studies have been made on Low-Site → Low-Site propagation
- Line-of-Sight models indicate a simple Distance-Squared propagation up until 30 m where it follows Distance-Fourth propagation

# Line-of-Sight Propagation Models

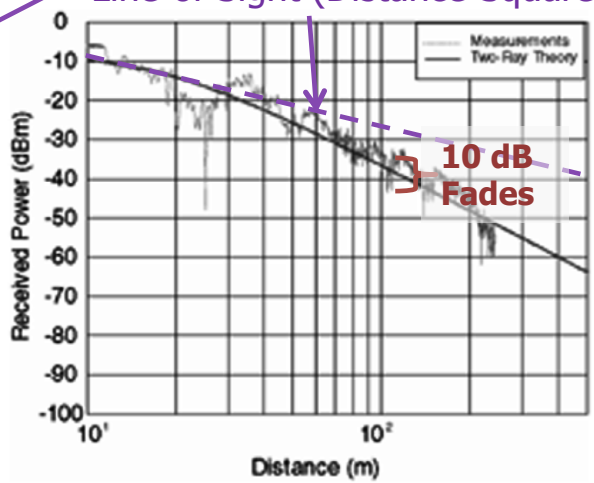
## (Impact of Frequency and Street Width)

Simple Model
Line-of-Sight (Distance-Squared)

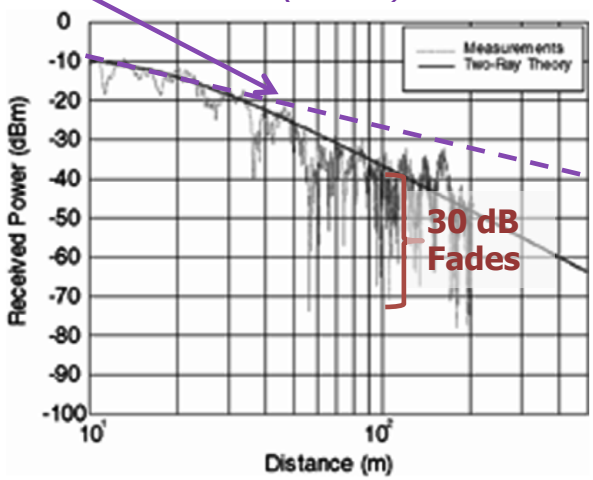
*1 Watt Transmitter (30 dBm)*




17 m Street @ 450 MHz
(11 λ)




6 m Street @ 225 MHz
(8 λ)




34 m Street @ 225 MHz
(45 λ)

- Frequency impact goes as Frequency-Squared
- Width of street goes as
  - Wider the street, larger multipath fades

# Non-Line-of-Sight Propagation Models

## (Impact of Turn and Distance from Transmitter)

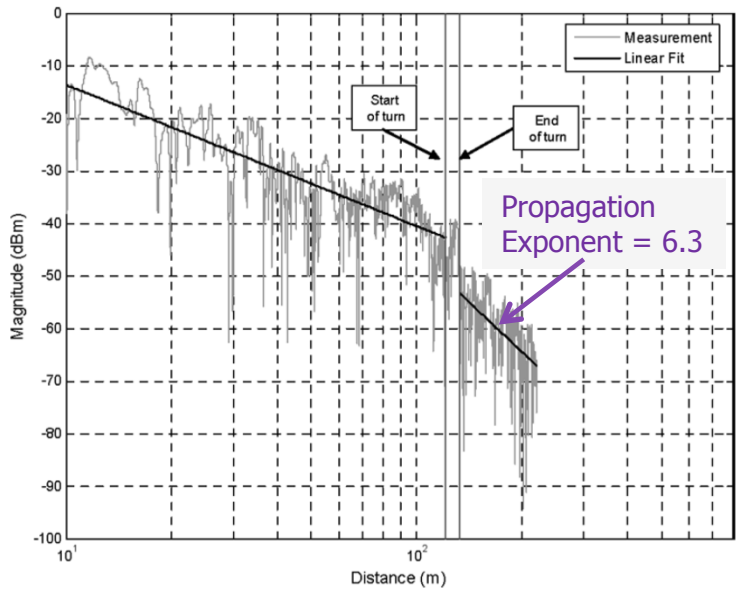



Fig. 5. Representative L-Path power level profile ($d_c = 132$ m).

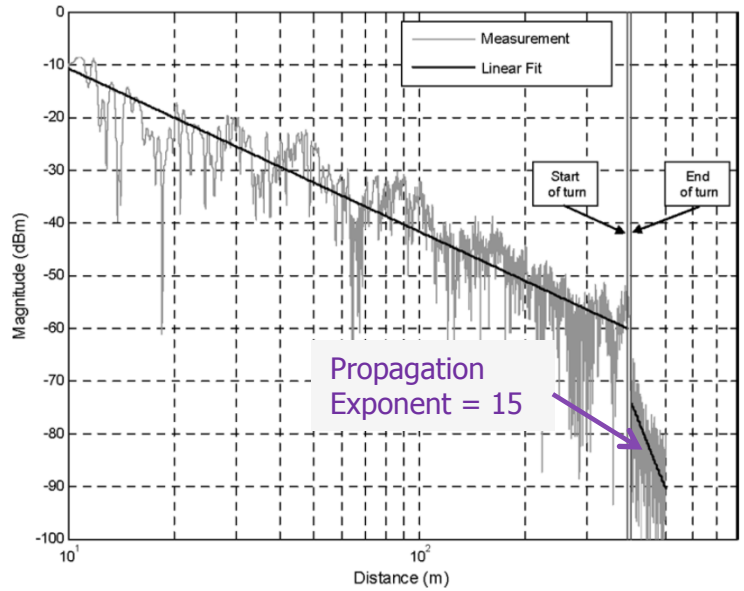



Fig. 7. Representative L-Path power level profile ($d_c = 400$ m).

- Non-Line-of-Sight significantly impacts range,
  - A single turn contributes 10-15 dB loss
  - Characteristics appear to be reproducible and somewhat deterministic

# Non-Line-of-Sight Propagation Models

## (Impact of Frequency)

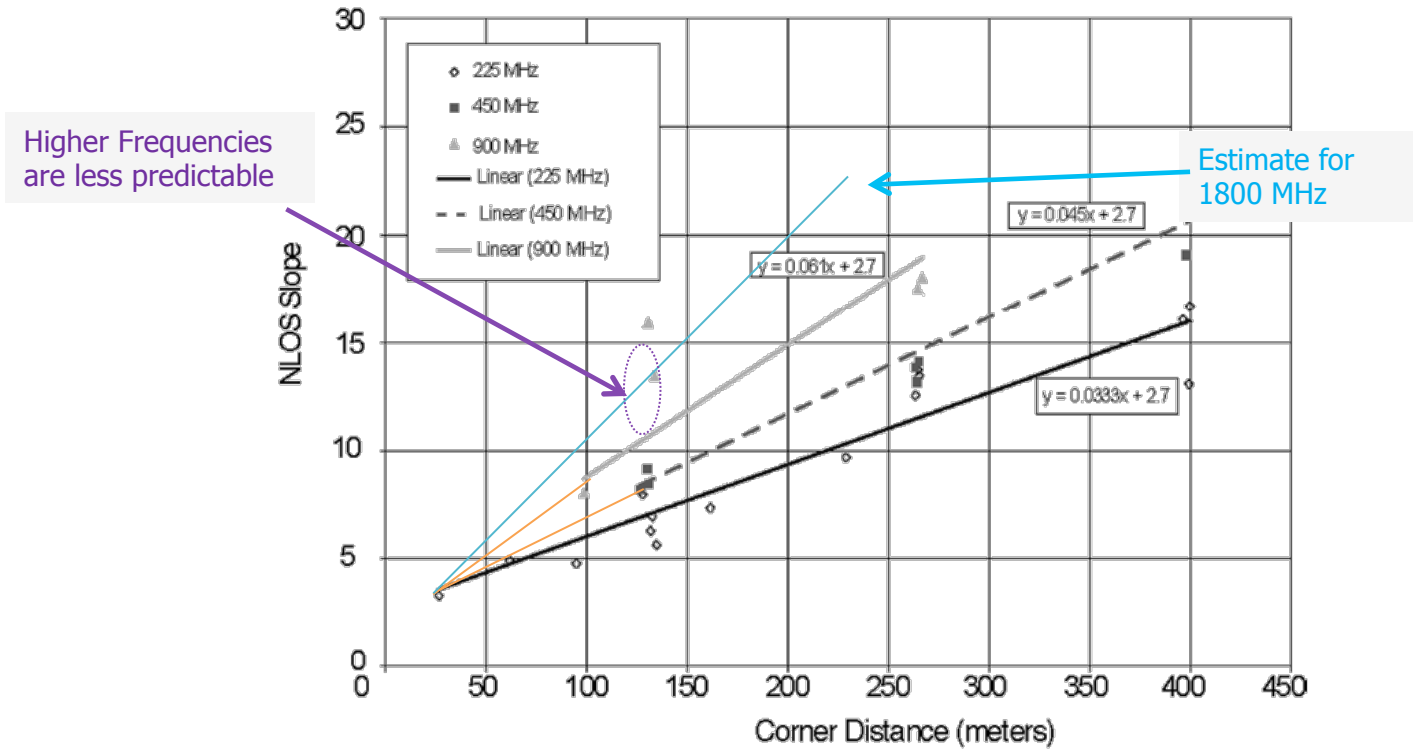



Fig. 9. NLOS slope versus corner distance separated out by frequency ($w_2 = 17$ m, $H_t = 2$ m).

- Non-Line-of-Sight is significantly impacted by frequency
- NLOS extinction slope ($P \propto R^{-\alpha}$, $Slope = d\alpha/d(corner\ distance)$ ) based upon a linear relationship between corner distance, frequency

# LOS vs NLOS Propagation

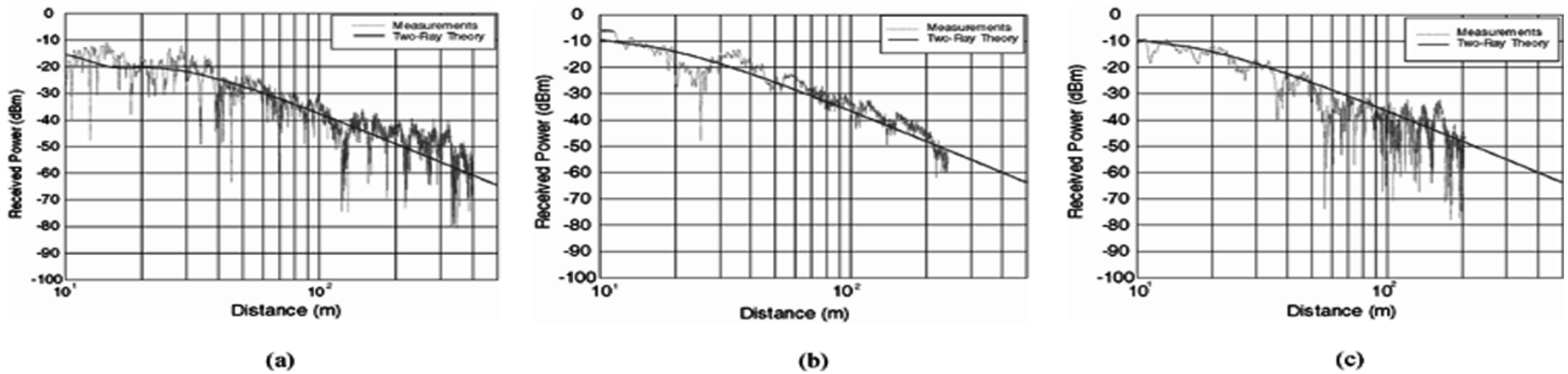



Fig. 4. Representative LOS profiles of received power versus distance. (a) $w_1 = 17$ m, $f = 450$ MHz; (b) $w_1 = 6$ m, $f = 225$ MHz; (c) $w_1 = 34$ m,

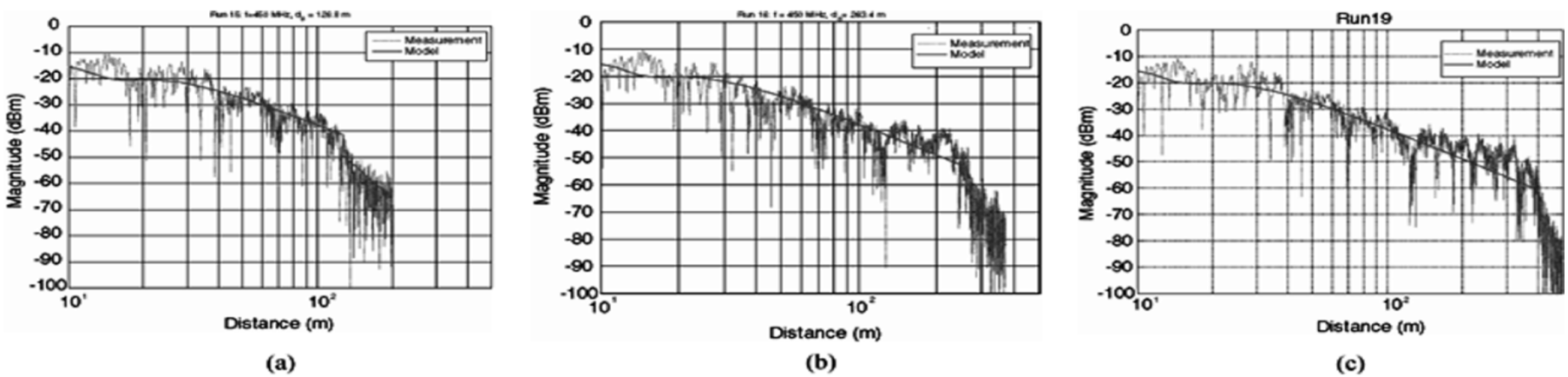



Fig. 15. Comparison between empirical model and measured data ($f = 450$ MHz, $H_t = 2$ m). (a) $d_c = 126.8$ m; (b) $d_c = 263.4$ m; (c) $d_c = 399.3$ m.

Propagation differences between LOS and NLOS provide new avenues of exploitation

# Summary

- Urban corridor propagation measurements indicate distinct signal strength versus distance characteristics

- There is a potential of developing new methods for exploiting a large, distributed measurement set (in time and in space) against a large distributed emitter set

# CONTACT INFORMATION

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# Public Release of Information

STO
Strategic Technology Office

- Proposed public disclosures of unclassified information regarding all DARPA efforts, shall be processed for approval prior to publication or distribution.

- One paper copy and one electronic copy on CD/ DVD must be submitted at least 20 working days prior to the requested date to DARPA's Technical Information Office, 3701 North Fairfax Drive, Arlington, VA 22203

# Classified Proposals

- SCG & DD254 will be released to performers who intend to submit a classified proposal
- Security guidance pertaining to this effort are derived from DARPA-SCG-740 (Draft)
- Request for SCG & DD254 *MUST* submit the formal request sheet via BAA mailbox

# Classified Proposals

- Proposal Process:
  - Ensure proposals are marked properly with correct classification (Header, Footer, and portion/para marking, graphics)
  - Methods of sending proposal:
    - USPS Express or Registered
    - Courier *(Must have courier card or letter on person)*
    - Include Performer Sheet List (Prime & Subs)
    - Close out Instructions

- Security Incidents:
  - Must notify DARPA within 24 hours! (even if you think it may be a potential incident)

# PROPOSALS

STO
Strategic Technology Office

- Proposal packages are due to DARPA NLT 4pm on *Monday, 16 April 2012*
- Please forward properly wrapped and marked package to:

## Inner Envelope

**DARPA**
**Attn: John Chapin**
**3701 North Fairfax Drive**
**Arlington, VA 22203**

## Outer Envelope

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