Multipath Exploitation Radar Industry Day

17 April 2009

Dr. Joseph Durek

Strategic Technology Office

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Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)

Introductions

Government

Joseph Durek	DARPA	Program Manager
Tina Stuard	DARPA	Contracting Officer
Robert Linnehan	AFRL/RYHE	SME

Support Staff

Gordon Miller	DARPA (ANSER)	SETA
Michael Papazoglou	Booz Allen Hamilton	SETA
Seelig Sinton	Booz Allen Hamilton	SETA

Agenda

- 0730 Check-in
- 0830 Proposer Day Presentations
  - Welcome — Joseph Durek
  - Contracting — Tina Stuard
  - Technical — Joseph Durek
  - MER Data — Robert Linnehan
  - Concluding Remarks — Joseph Durek
- 1130 Sidebars with PM

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Contracting

Tina Stuard

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DARPA-BAA-09-01

Solicitation is released utilizing Broad Agency Announcement procedures IAW FAR 35.016

- ELEMENTS OF THE BAA
  - Synopsis in FEDBIZOPPS
  - “Add to Watch List” to get any update notices
- TIME PERIOD(S) –
  - BAA is open through 12 Mar 2010
  - Initial proposals due **22 May 2009**
  - Proposals received after 22 May 2009 will be evaluated/selected based on availability of subsequent program funding

BAA PROCESS

- ELIGIBILITY
  - All interested/qualified sources
  - Foreign participants/resources may participate to the extent authorized by applicable Security Regulations, Export Laws, etc.
  - Government agencies/labs, FFRDC's, are subject to direct competition limitations and cannot respond unless they demonstrate work is not otherwise available and cite the specific statutory authority

BAA PROCESS

- PROPOSAL PREPARATION/SUBMISSION
  - Instructions are detailed in the BAA (**Follow closely**)
  - **ALL** questions to DARPA-BAA-09-01@darpa.mil
  - Funding instruments = primarily contract(s) and other transactions, no assistance instruments (grants, cooperative agreements)
- Assert rights to **all** technical data & computer software generated, developed, and/or delivered to which the Government will receive less than Unlimited Rights
  - Assertions that apply to Prime and Subs
  - Use defined "Basis of Assertion" and "Rights Category"
  - **Justify** "Basis of Assertion"
  - **This information is assessed during evaluations**

BAA PROCESS

- Volume I Technical/Management Proposal
  - Mind Page Limitations (**don't use Cost Prop for overflow)**
  - SOW (by WBS, milestones, deliverables, exit criteria)
- Volume II Cost Prop
  - Provide **all** Cover Page info
  - FAR Part 15.4/Table 15-2 (suggested format/content)
  - Provide BOE(s) to support proposed costs (labor & material)
  - **Include all** subcontract proposals

Following the proposal instructions assists the evaluation team to clearly understand what is being proposed.

Following the proposal instructions supports a timely negotiation.

BAA PROCESS

EVALUATION/AWARD

- Government reserves the right to select for award all, some, or none of the proposals received.
- Government anticipates making multiple awards
- No common Statement of Work - Proposals evaluated on individual merit and relevance as it relates to the stated research goals/objectives rather than against each other
- Once selections are made, proposals are provided to the Contracting Officer in preparation for negotiations
- Only authorized Contracting Officer may obligate the Government

BAA PROCESS

COMMUNICATIONS

- Prior to receipt of proposals – No restrictions, however Gov't (PM/PCO) shall not dictate solutions or transfer technology

  After Receipt of Proposals – Government (PM/PCO) may communicate with offerors in order to understand the meaning of some aspect of the proposal that is not clear or to obtain confirmation or substantiation of a proposed approach, solution, or cost estimate

- Informal feedback may be provided once selection(s) are made

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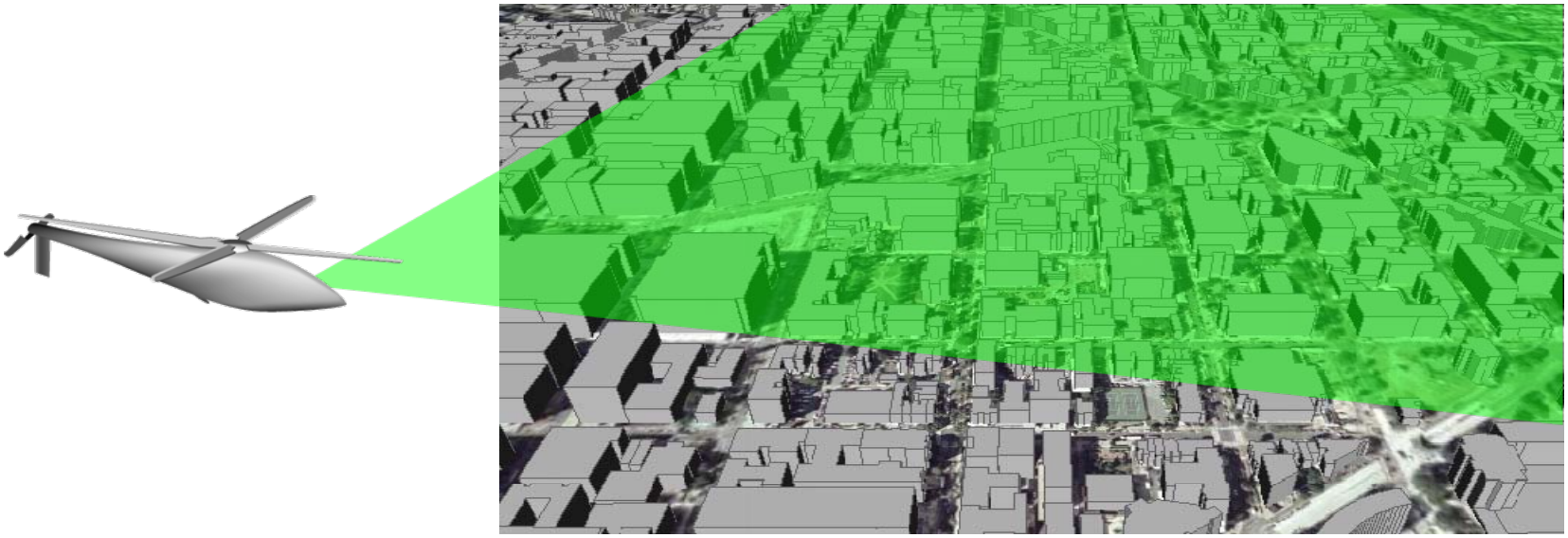
Program Vision: Multipath Exploitation Radar for Urban Tracking



Multipath Exploitation Radar can provide *persistent* wide area tracking of vehicles in a metropolitan area like Baghdad using only three UAVs at 15 kft altitude

- Track high value targets through dense city streets without direct line-of-sight
- Provide long-term track history of all targets for post-event forensics

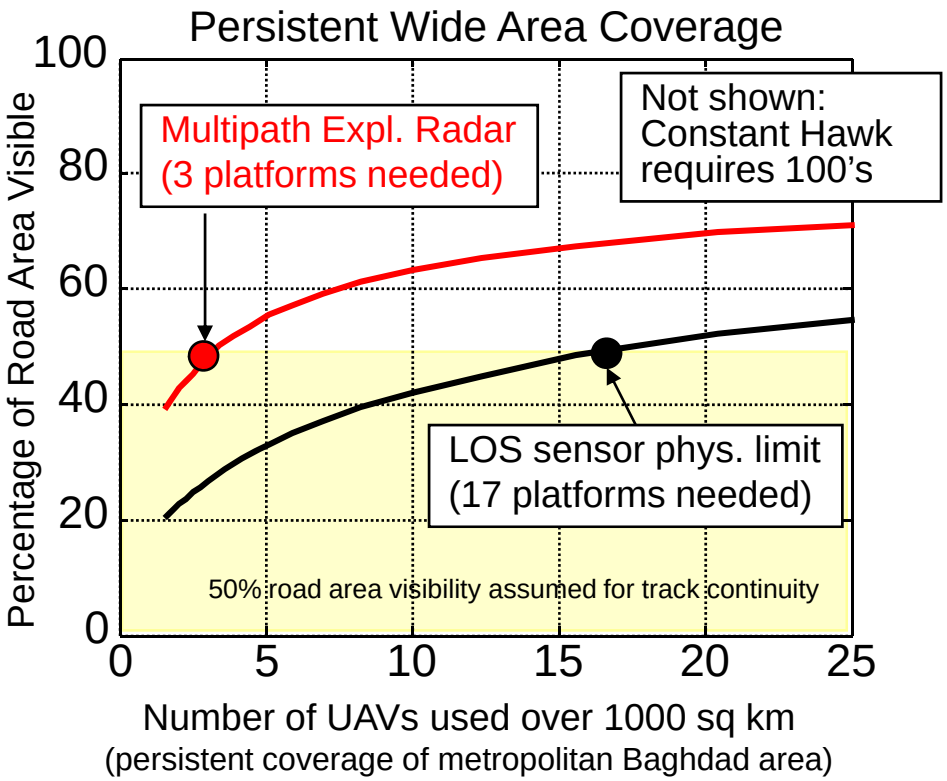
Enabling technology uses specular multipath off buildings to see into urban shadows and canyons

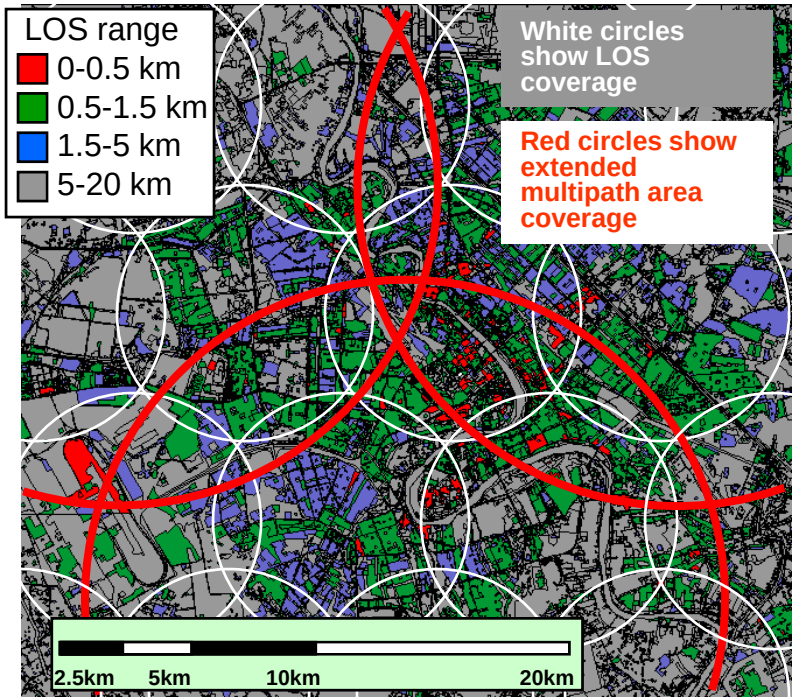
- Provides six-fold increase in sensor coverage area over physical line-of-sight limit

Multipath Exploitation Radar can cover entire Baghdad metropolitan area with three multipath exploiting airborne sensors!

Multipath Exploitation Area Coverage

- **UAVs at 15 kft will have line-of-sight (LOS) blockages that limit their range to 5 km or less over metropolitan area (optics limitations can be significantly less)**
- **Specular multipath off buildings can extend the sensor range up to 12-15 km to fill in urban shadows**





Baghdad showing coverage area of LOS (in white) vs Multipath radar (in red)

Multipath Exploitation Radar can provide wide area urban surveillance, reduce platform count significantly over LOS systems

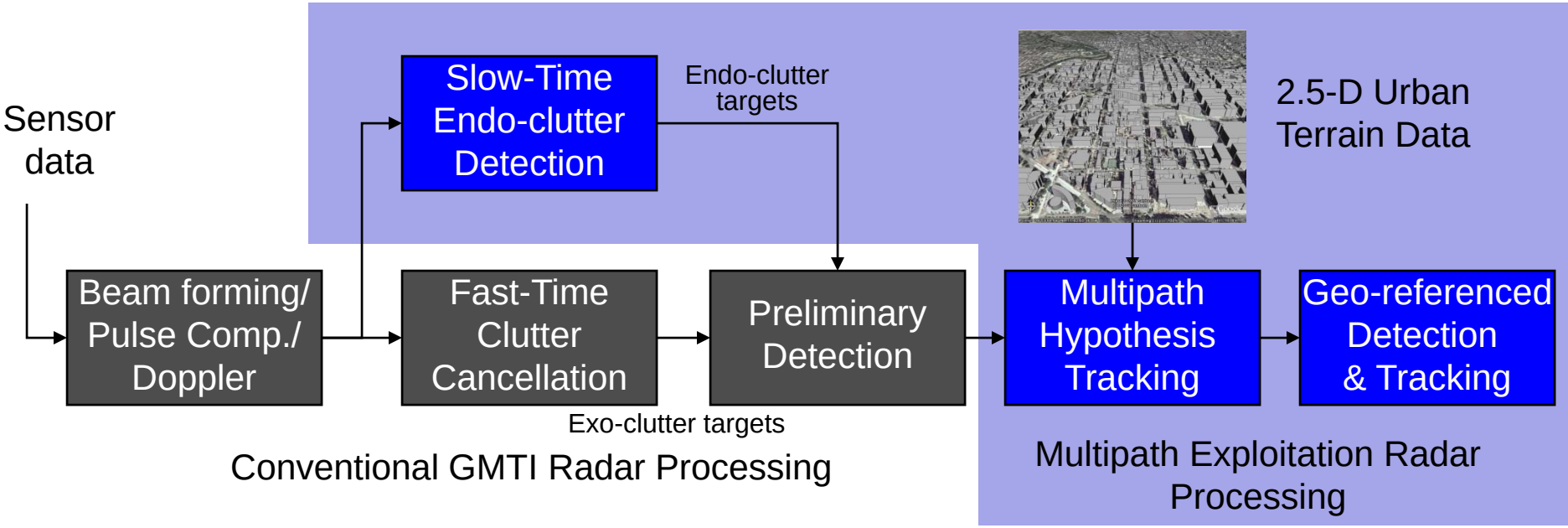
Multipath Exploitation Approach

Multipath urban tracking can be demonstrated as a post-processor adjunct to a GMTI radar

- Conventional GMTI reports feed a multipath hypothesis model using detailed information of the urban terrain and Viterbi paths through a hidden Markov model
- Endo-clutter signatures may be extractable from change detection of short-CPI dwells

Multipath exploitation enabled by detailed urban model and efficient ray-tracing processors

- Overhead LIDAR maps can provide 2.5-D urban terrain information
- Specular multipath predictions ideally suited for graphical processing unit (GPU) ray-tracing engines (ray racing only required in vicinity of detected targets)



Multipath exploitation can be demonstrated with existing GMTI radars

Outline

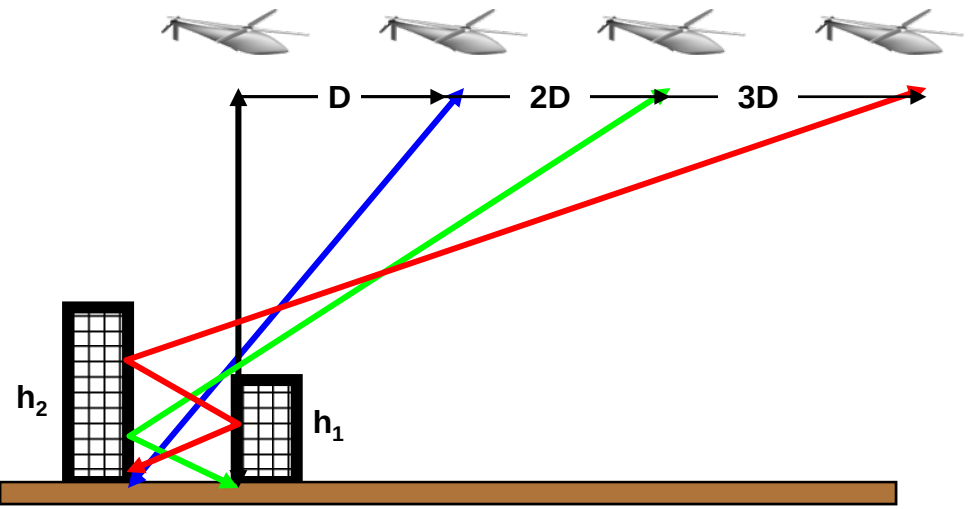
Multipath exploitation radar concept

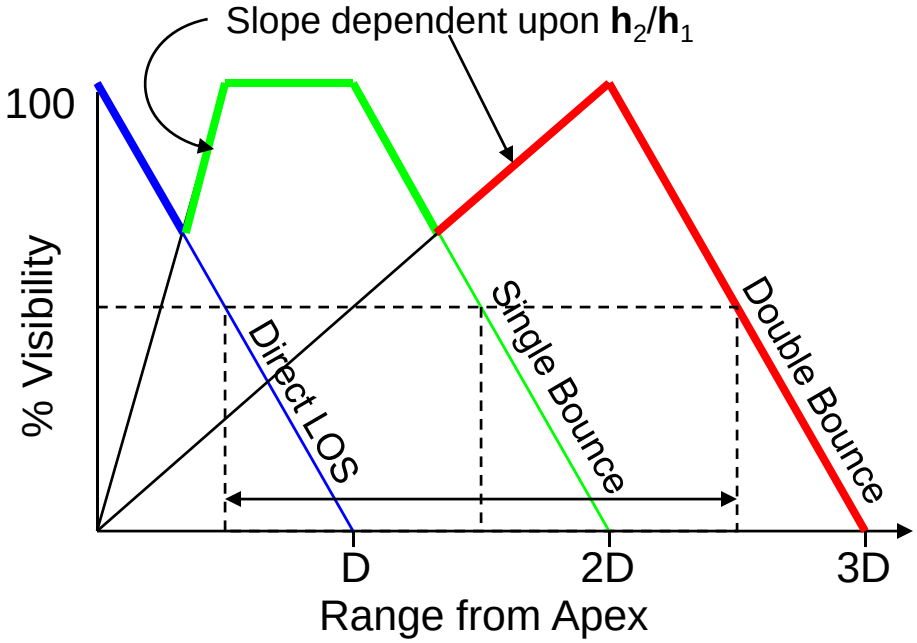
Technical issues:

- Phenomenology
- Tracking
- System architecture

Program plan

Geometry of RF Multipath





As platform moves from apex, visibility decreases linearly with distance

- 50% road coverage up to 0.5 D (where D is the range to complete LOS blockage)

Single bounce multipath starts to fill in shadowed area

- 50% road coverage up to 1.5 D (three times the LOS range, nine times the LOS area)

Double bounce multipath also possible

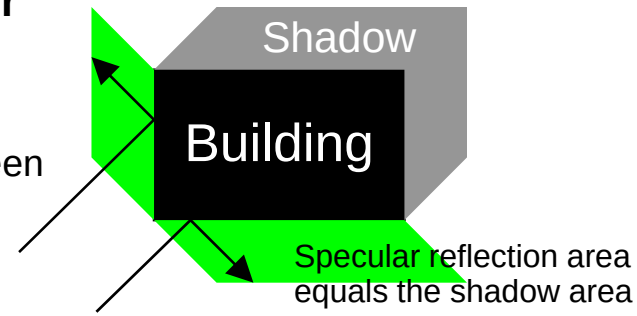
- 50% road coverage up to 2.5 D (five times the LOS range, 25 times the LOS area)
- Higher order multipath generally bounces away

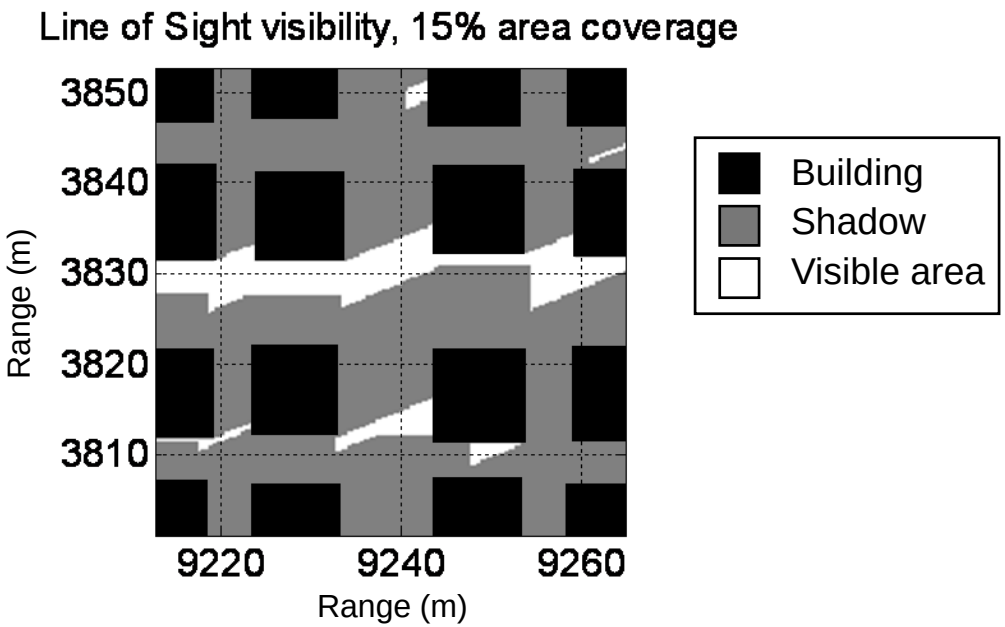
Multipath can increase sensor area coverage by a factor of 9-25!

Line of Sight vs. Multipath Coverage

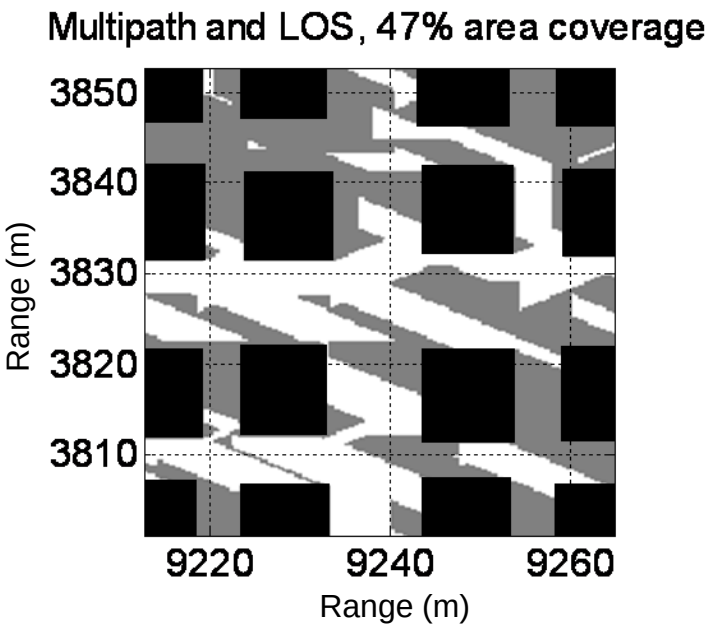
Example: Surveillance of a typical urban scene (two to four story buildings) as seen by 15 kft UAV

- Top down view of typical city block shown
- Line-of-sight shadows dramatically reduce visibility of roads between buildings
- Multipath fills in the shadows





Urban shadows are fatal for line-of-sight systems



Specular reflections from buildings fill urban shadows and increase road visibility

Specular reflection allows detection within urban canyons

Wide Area Urban Tracking Possible Approaches

Wide area urban tracking could be done today, but would be prohibitively expensive

Primary limitations to existing technology are Line-of-Sight (LOS) access

- Airborne requirements: Large network of airborne assets with limited field of view EO payloads required to see down into urban canyons
- Ground: Requires cameras at almost every street corner

Multipath Exploitation Radar breaks through the LOS restriction

- Multipath reflections allow farther standoff, greatly reducing the number of platforms for wide area coverage
- This is enabled by rapidly developing knowledge of the urban terrain (e.g., LIDAR maps) and GPU processors tailor-made for specular ray-tracing

	Current approaches		Proposed Approach
Parameter	**Overhead Assets**	**Ground-based Imagery**	**Multipath Exploiting Radar**
Platforms needed to cover city	Scores of A160s/Predators	100's of emplaced cameras	Three A160s/Predators
Sensor	EO/IR	EO/IR	Wide-area radar
Persistent urban coverage area	1-4 sq km	1-10 sq km	1000 sq km
Sensor range	<5 km (limited by line-of-sight)	~1 km down roads	~15 km

Multipath Exploitation Radar can enable cost-effective urban surveillance over wide urban areas

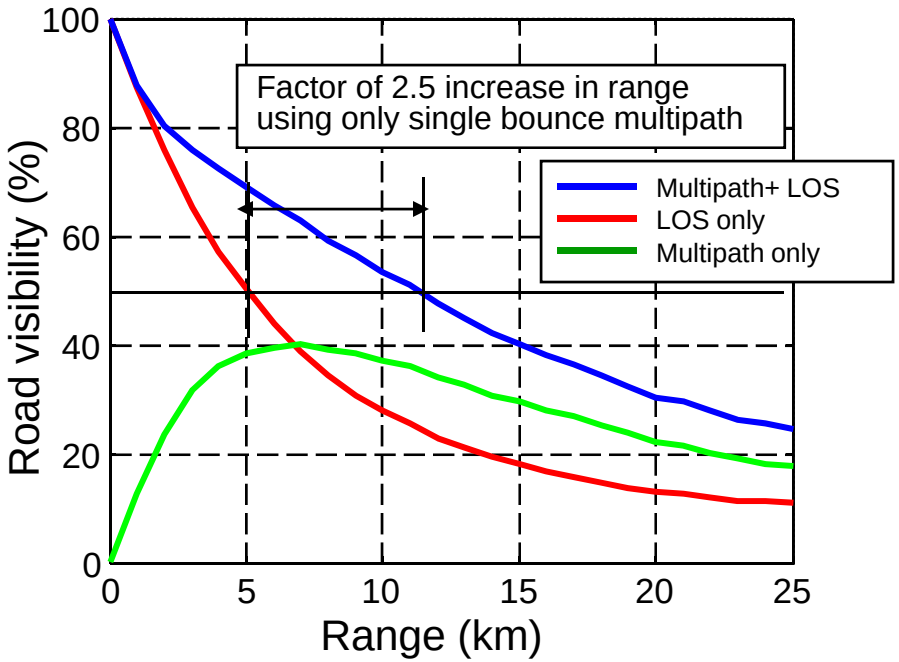
Airborne Sensor Range Extended Using Multipath

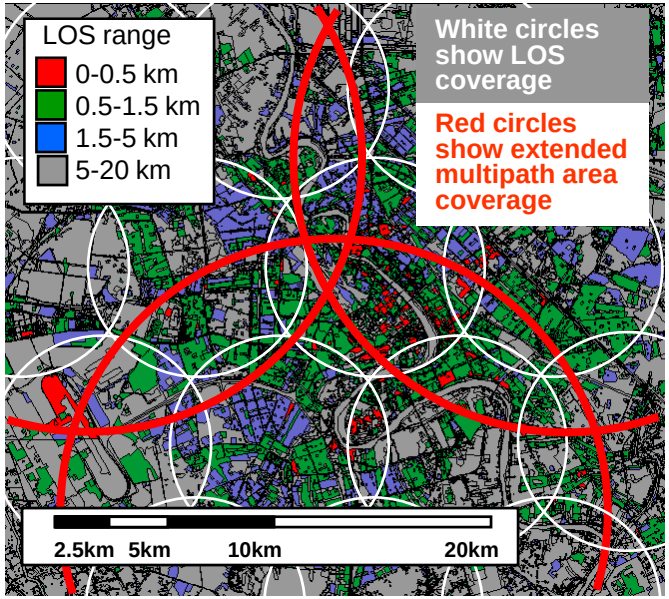
Statistical sampling performed to validate line-of-site (LOS) vs. multipath coverage

- Stationary radar at 15 kft looked at random building profiles with varied heights and look angles to compute mean percentage of road area visible by LOS and multipath
- 50% road visibility used as an estimate for tracking requirements

Single-bounce multipath increases sensor range by a factor of 2.5, leading to a factor of six improvement in area coverage (the square of the range coverage)

- Higher-order multipath is not modeled, but may further increase area coverage improvement





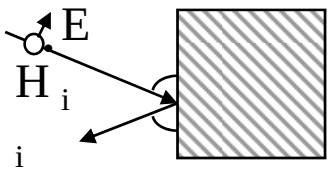
Baghdad Metropolitan area

MER offers an area coverage improvement of a factor of six over physical LOS limits

Specular Reflection Theory

- Multipath exploitation radar concept based on modeling predictable specular reflections off of buildings
- Predicted and modeled scattering data confirms that specular reflections off of typical urban building materials are much stronger than diffuse scattering

VV Pol, , E^{TE}



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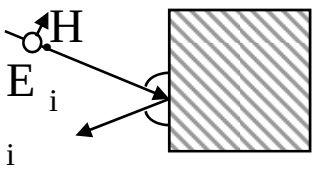

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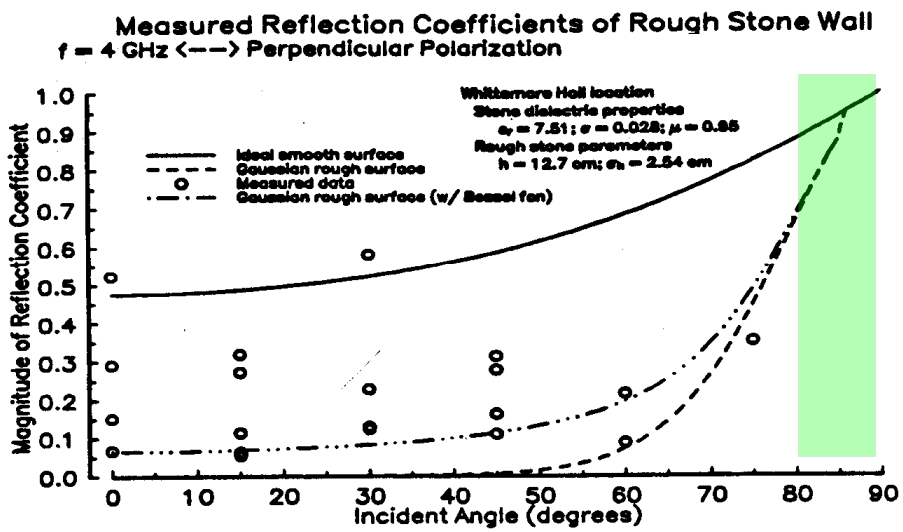
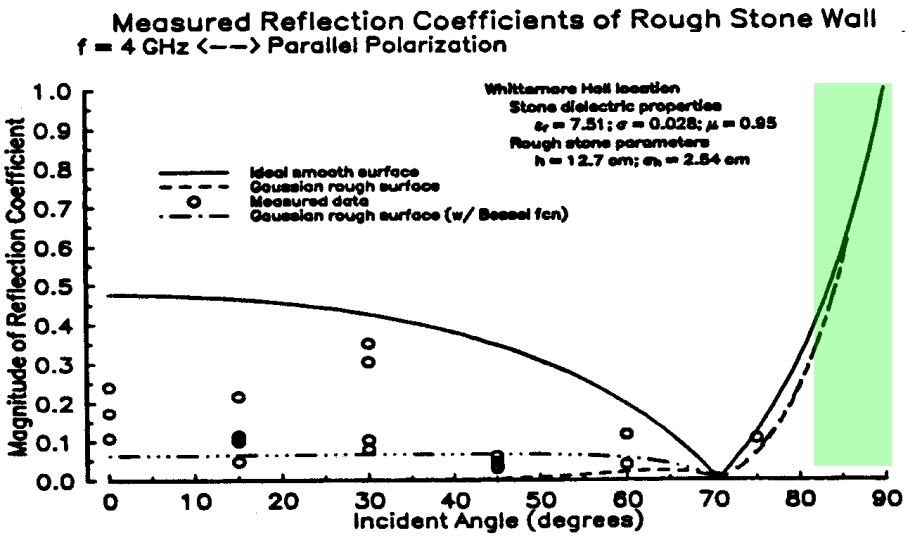


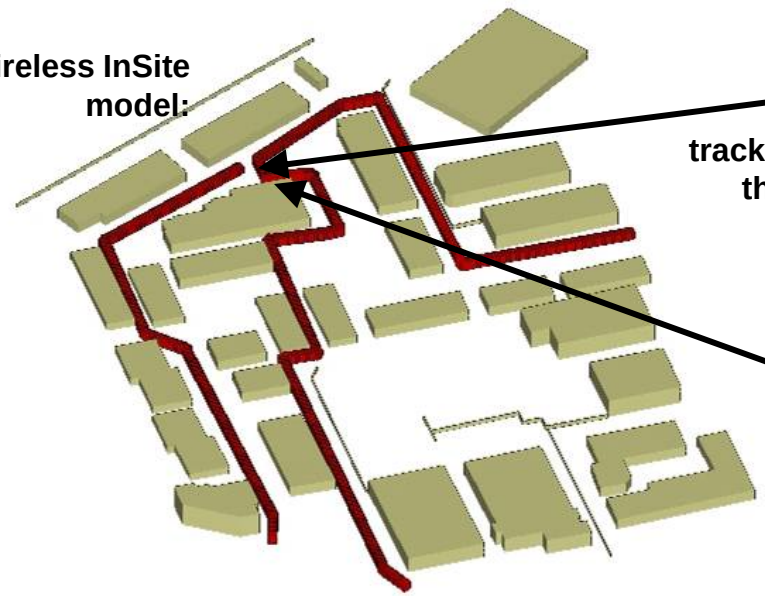


Theory predicts that specular reflections will have a dominant effect in multipath exploitation radar, while diffuse scattering effects will be minimal

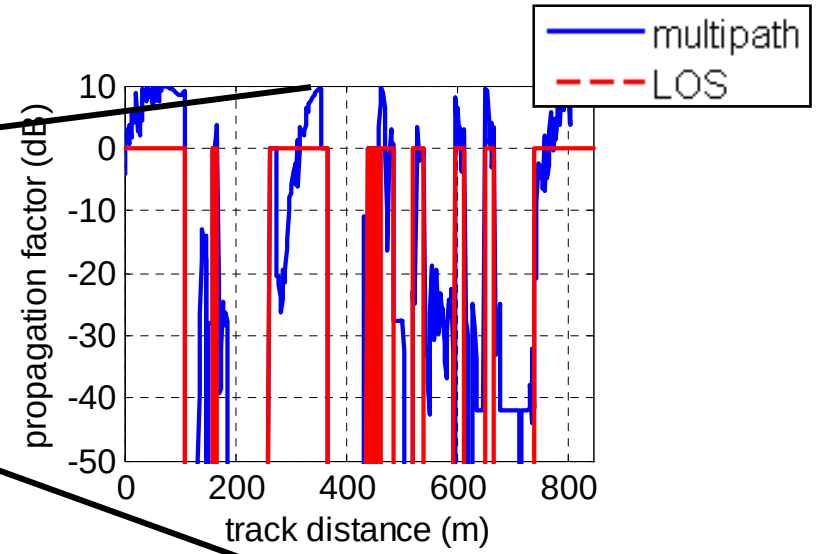
Target Simulation for Vehicle Track through Sample Urban Environment

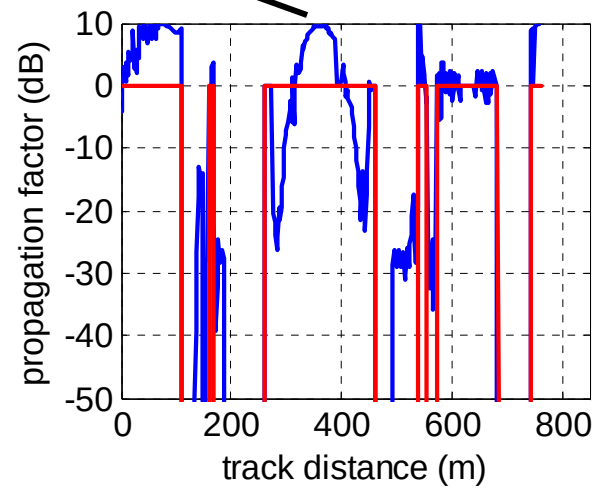
Urban environment simulation with 14 degree depression angle from sensor platform to vehicle target

Wireless InSite model:



tracks deviate at this point





Building layout and target routes derived from area imagery

InSite simulation parameters

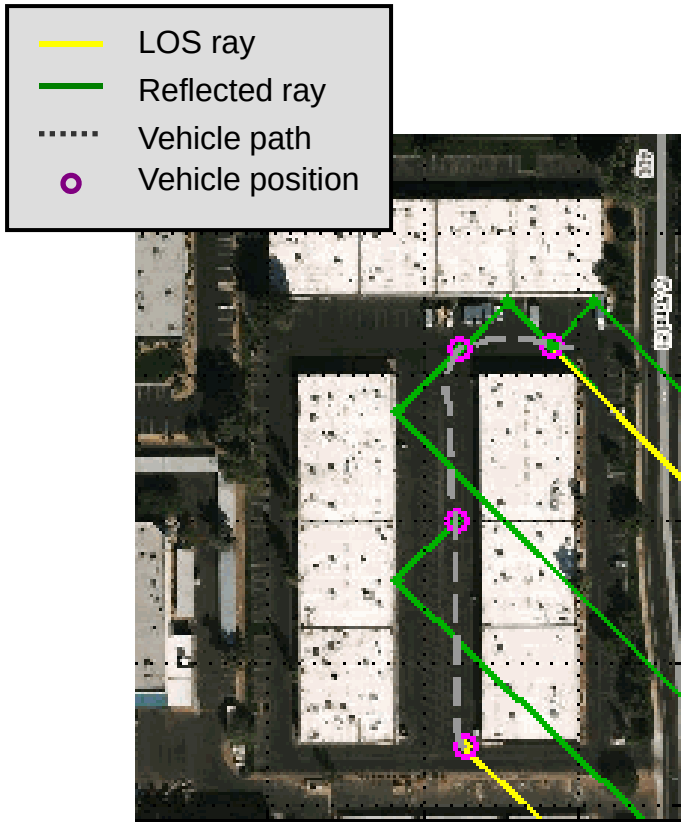
- SBR propagation, with ray spacing = 0.01 degrees
- only reflection EM interactions allowed (maximum 4 per propagation path)

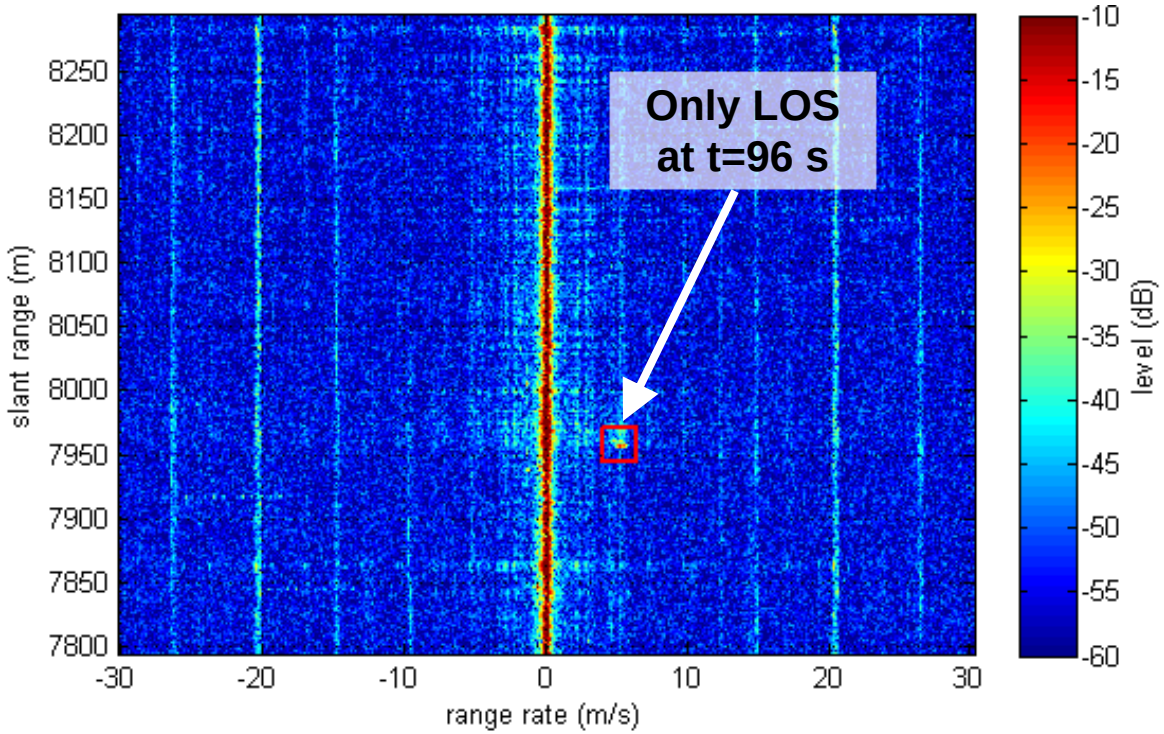
Carports, trees, and any other objects (e.g. crates and trucks seen in Google Earth image) are not modeled

MER Data Collection Example: Urban Multipath Structure

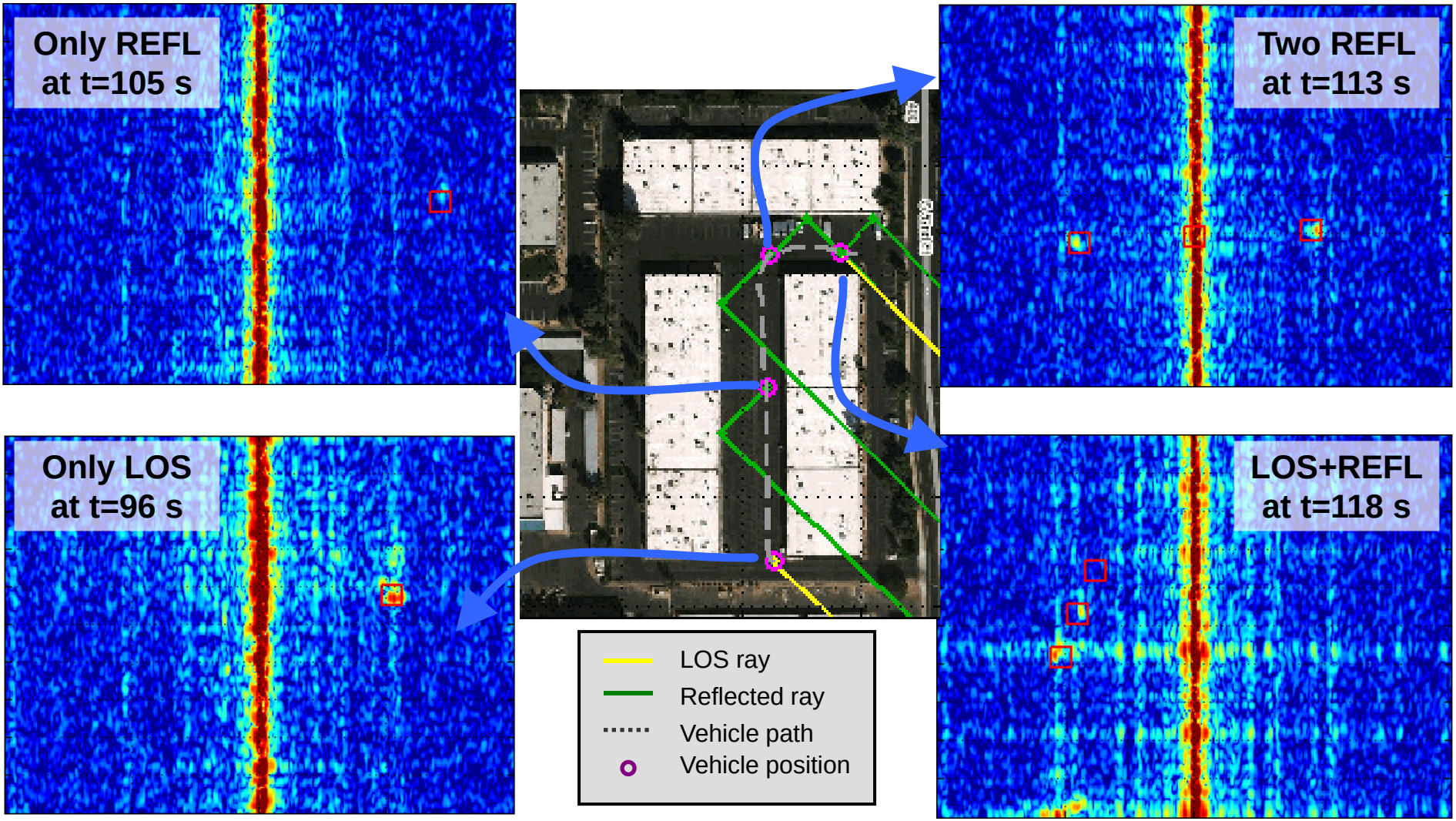
Sample collection demonstrates impact of multipath propagation on target range-Doppler signature

As vehicle travels along path between two buildings, multipath return structure changes at different vehicle positions





MER Data Collection Example: Urban Multipath Structure

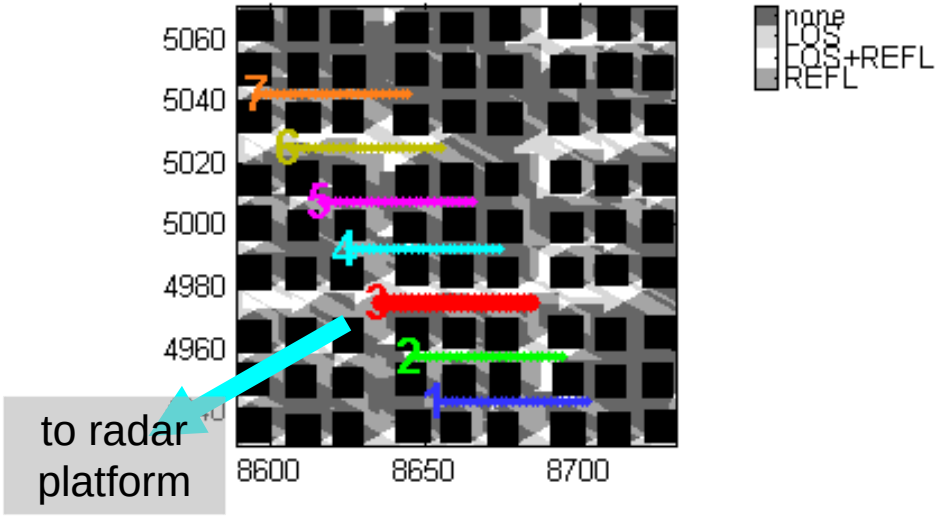


Target's Range-Doppler signature can be matched to urban profile

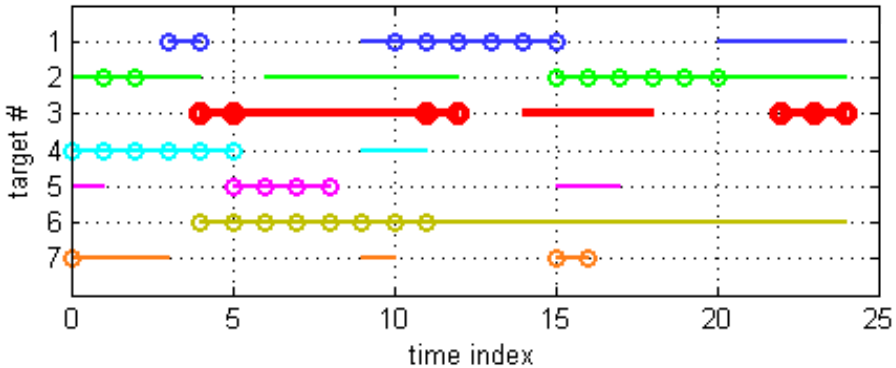
Multipath Hypothesis Tracking

- Simulation of ambiguous tracks at same range from radar platform moving at equal velocities (targets moving east) demonstrates ability to discriminate different targets within the same beam
- Range-Doppler fingerprints from multipath reflection structures for different tracks are unique

Target tracks overlaid on urban layout:



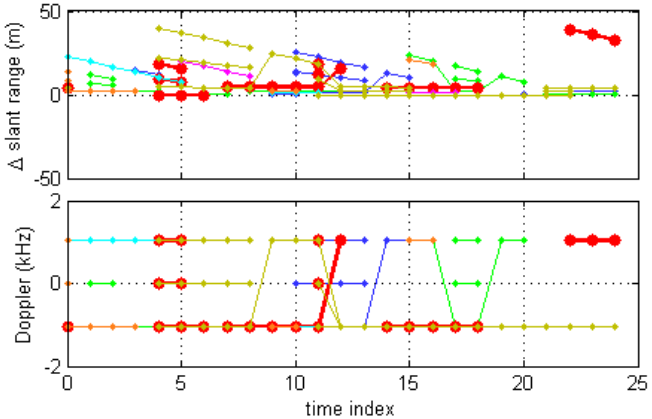
Track coverage vs. time:



Line indicates target detected, circle indicates multiple detections (e.g., LOS+ multipath)

Slant range and Doppler histories:

(colors match tracks 1 to 7 from above layout)



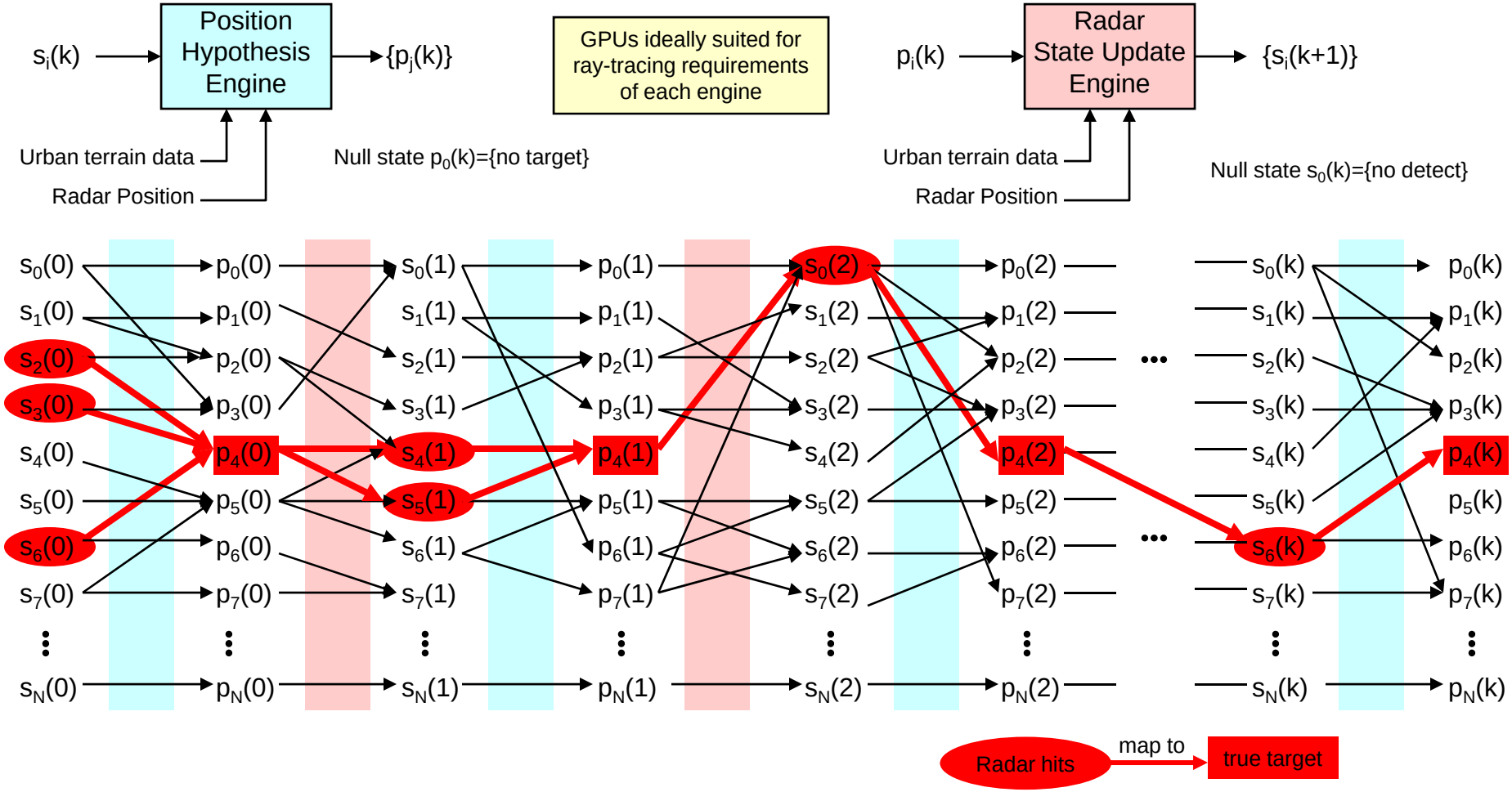
Multipath returns provide fingerprint identifiable to urban location

Multipath Hypothesis Tracking

Viterbi Chains Through Hidden Markov Models

Each radar state vector $s_i(k)$={range, doppler} at time k may have multiple allowable position states $\{p_j(k)\}$

Each position state vector $p_j(k)=\{x,y,v_x,v_y\}$ at time k may project forward into multiple allowable radar states $\{s_j(k)\}$



Viterbi chains uniquely connect radar detection fingerprints with true track locations

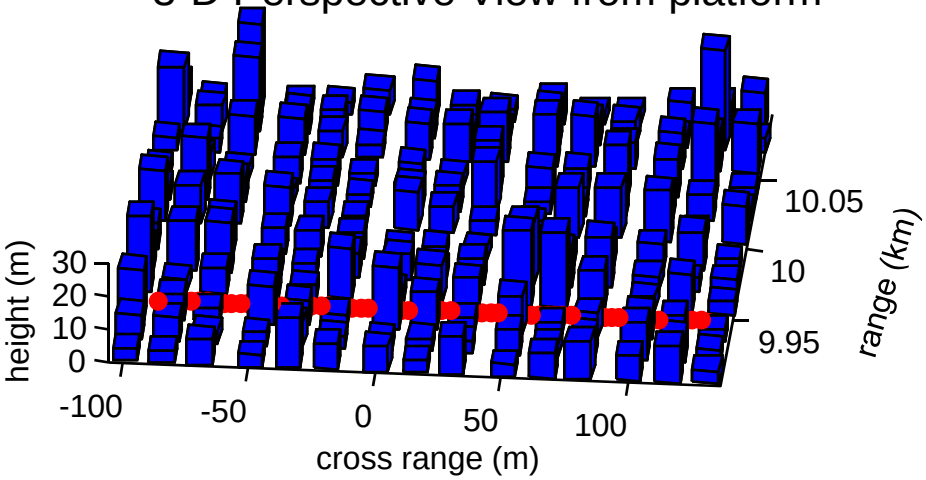
Slow-Time Endo-Clutter Detection

Simulation of radar illumination from the south with target moving tangential to radar platform

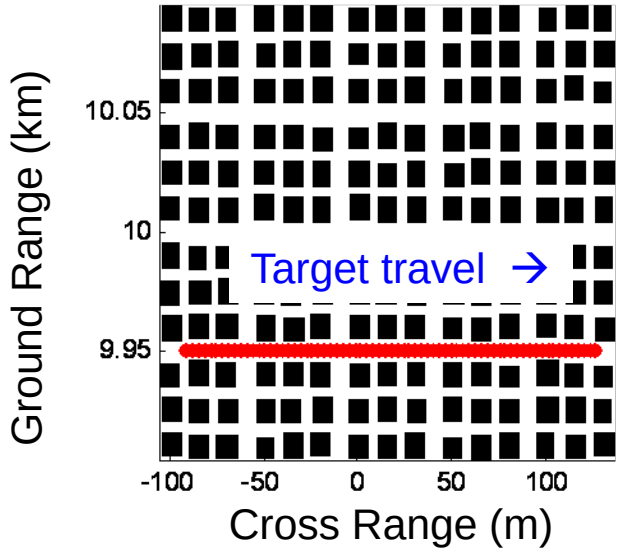
LOS returns have no Doppler offset, but non-LOS returns demonstrate range-Doppler history dependent upon building profile

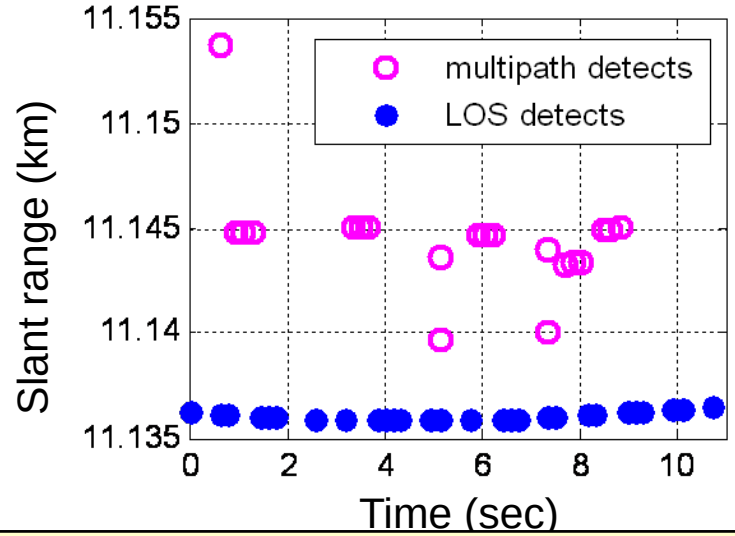
Measured profiles can be matched against building profile templates to fix vehicle locations to within a city block

3-D Perspective View from platform



Overhead View of Traversal





Non-LOS paths allow for target detection even for low-Doppler LOS geometry

Architecture Assumptions

Architecture trade space predicated by tracking assumptions

- Track fingerprints require sampling on the order of building length

Parameter	Assumption	Derived value
Range resolution	Direct and multipath returns should be separable by several range cells	1.5 m
Max. ground track velocity	Capture high speed vehicles within city environment (~60 mph/~100 kph)	30 m/s
Dist. between track revisits	Vehicle travel between revisits on the order of building length to exploit urban fingerprinting	5 m
Min. Detect. Velocity	Reduce clutter notch width	0.5 m/s

- UAVs at 15 kft deemed to provide safe low cost coverage of urban areas
  - Platform options available include A160 or Predator
  - Stationary platform preferred for early concept demonstrations without added complexity of space-time adaptive clutter nulling

Stationary UAV (e.g., A160)	Moving UAV (e.g., Predator)
Easier clutter nulling	Urban space-time adaptive clutter nulling required
Quasi-static multipath model	Dynamic multipath model
Limited scene diversity	Changing scene diversity

- Desire radar frequencies with predominantly specular scattering off of buildings
  - X, Ku, or Ka band radars

Multipath Exploitation Radar Collection

DARPA has collected airborne radar data for a controlled environment

- Ku-band next generation targeting system (NGTS) radar (operated by Lockheed Martin)
- Radar mounted on UH-1 Helicopter used for collections with both (nearly) stationary and moving platform

Data Collection Summary:

- Collected data in urban environment with up to three instrumented vehicles in the collection area
- Successful collection of 29 two-minute collection intervals
- Presence of multipath phenomenology has been confirmed

Data will be provided for MER algorithm development tasks

- Full data documentation provided
- Further details in AFRL brief

Operational Parameters		
Range Resolution	1.5	m
Max. vehicle velocity	30.2	m/s
Min. Det. Vel.	0.25	m/s
System Parameters		
Frequency	16.9	GHz
BW	120	MHz
Wavelength	0.018	m
Maximum Doppler	3400	Hz
PRF	6800	Hz
PRI	1.47E-04	s
Unambiguous range	22.1	km
CPI duration	0.036	s
CPI length	256	pulses
Transmit power	24.8	dBW
Transmit array gain	35.8	dB
Receive array gain	35.8	dB
Beamwidth Azimuth	2.1	deg
Beamwidth Elevation	2.6	deg
Target RCS	10	dB
Mulitpath loss	5	dB
System losses	5.3	dB
Noise power	-123.5	dB
Slant Range	8.67	km
SNR per pulse	-5.9	dB
Duty cycle	0.036	
Processing gain	52.1	dB
Target SNR	46.2	dB

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Multipath Exploitation Radar Goals and Tasks

Goal: develop, demonstrate, and quantify the performance of algorithms for non-line-of-sight detection and tracking of multiple vehicles through urban canyons using radar data provided by DARPA

Program Tasks:

1. **Target and clutter signature development:** demonstrate the detection states (occluded, LOS, non-LOS) of moving vehicles driving through urban terrain using the DARPA-provided Ku-band radar data
2. **Tracking algorithm development:** develop tracking algorithms for handling unique multipath-dependent range-Doppler profiles, incorporating knowledge of the urban terrain and accounting for multipath propagation conditions
3. **System concept development:** develop an architecture concept that is extendable to persistent wide-area urban tracking over 1000 sq. km with less than five radar platforms

Multipath Exploitation Radar
Task 1

Task 1: Target and clutter signature development

The performer will demonstrate the detection states (occluded, LOS, non-LOS) of moving vehicles driving through urban terrain using the DARPA-provided Ku-band radar data. As part of this demonstration, error bounds on detection and localization performance will be developed based upon the precision of urban models and radar registration. This analysis will be done using the collected data when the helicopter was hovering as well as when it was moving. This task will also address the development of Space-time adaptive processing (STAP) clutter-nulling approaches that are appropriate for multipath environments. The accuracy requirements on urban terrain knowledge necessary to achieve the program goals will be determined.

Task 2: Tracking Algorithm Development

The performer will develop tracking algorithms for handling unique multipath-dependent range-Doppler profiles, incorporating knowledge of the urban terrain and accounting for multipath propagation conditions. A key challenge of this task will be to determine the uniqueness and separability of target tracks using urban multipath fingerprinting, and the resulting localization accuracy that is achievable. The performer will also ultimately determine limits on track accuracy, persistence, and density that can be achieved. Performance of tracking algorithms developed in this task will be evaluated using the airborne radar data made available as GFI.

Task 3: System Concept Development

The performer will develop an architecture concept that is extendable to persistent wide-area urban tracking over 1000 sq. km with less than five radar platforms. The performer will quantify the requirements for both the radar and data processing systems and identify potential platforms that meet these requirements.

Multipath Exploitation Radar Program Metrics

Program Metrics:

Task	Standard
Detection Improvement	2.5 times increase in sensor range compared to LOS coverage measured at 50% probability of detection
Tracking of multiple vehicles	1 vehicle per 100 m of road
Cross-range localization	50 m at 10 km range
Track continuity	>50% track visibility over increased LOS + non-LOS coverage area
	Demonstrate sparse traffic tracking with dropouts less than 50 m in duration

Evaluation Criteria

Evaluation of proposals will be accomplished through a scientific/technical review of each proposal using the following criteria, in order of descending importance:

1. Ability to Meet Program Go/No-Go Metrics
2. Overall Scientific and Technical Merit
3. Potential Contribution and Relevance to the DARPA Mission
4. Realism of Proposed Schedule
5. Proposer's Capabilities and/or Related Experience
6. Plans and Capability to Accomplish Technology Transition
7. Cost Realism

1. Ability to Meet Program Go/No-Go Metrics

The proposal clearly explains the technical approach(es) that will be employed to meet or exceed each program metric listed in Section 1.2 Program Metrics. The feasibility and likelihood of the proposed approach for satisfying the program go/no-go metrics are explicitly described and clearly substantiated. The proposal reflects a mature and quantitative understanding of the performance go/no-go metrics, the statistical confidence with which they may be measured, and their relationship to the concept of operations that will result from successful performance in the program.

2. Overall Scientific and Technical Merit

The proposed approach is supported by a technical description and rationale showing it to be feasible, achievable, and complete. Task descriptions and associated technical elements provided are complete and in a logical sequence with all proposed deliverables clearly defined such that a final product that achieves the goal can be expected as a result of award. The proposal clearly identifies major technical risks and planned mitigation efforts and provides ample justification as to why the approach(es) is / are feasible.

3. Potential Contribution and Relevance to the DARPA Mission

The potential contributions of the proposed effort with relevance to the national technology base will be evaluated. Specifically, DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use.

4. Realism of Proposed Schedule

The proposer's abilities to aggressively pursue performance metrics in the shortest timeframe and to accurately account for that timeframe will be evaluated, as well as proposer's ability to understand, identify, and mitigate any potential risk in schedule.

5. Proposer's Capabilities and/or Related Experience

The proposer's assembled technical team has the expertise and experience to accomplish their proposed tasks. The proposer's prior experience in similar efforts clearly demonstrates an ability to deliver products that meet the proposed technical performance within the proposed budget and schedule. The proposed team's expertise to manage the cost and schedule will be evaluated. Similar efforts completed/ongoing by the proposer in this area are fully described including identification of other Government sponsors.

6. Plans and Capability to Accomplish Technology Transition

The capability to transition the technology to the research, industrial, and operational military communities in such a way as to enhance U.S. defense, and the extent to which intellectual property rights limitations creates a barrier to technology transition.

7. Cost Realism

The objective of this criterion is to establish that the proposed costs are realistic for the technical and management approach offered, as well as to determine the proposer's practical understanding of the effort. This will be principally measured by cost per labor-hour and number of labor-hours proposed. The evaluation criterion recognize that undue emphasis on cost may motivate proposers to offer low-risk ideas with minimum uncertainty and to staff the effort with junior personnel in order to be in a more competitive posture. DARPA discourages such cost strategies. Cost reduction approaches that will be received favorably include innovative management concepts that maximize direct funding for technology and limit diversion of funds into overhead.

Multipath Exploitation Radar Summary

Urban tracking severely limited by line-of-sight (LOS) restrictions

Radar multipath sees into urban shadows and overcomes LOS limits

- Sensor area coverage can be increased by a factor of six
- Unique multipath fingerprints can be mapped back to urban location providing sub-beamwidth localization
- Urban tracking can be demonstrated as a back-end upgrade of existing GMTI systems
  - Full persistent wide area tracking will require more significant radar modifications

DARPA has collected airborne radar data in an urban environment that exhibits multipath phenomenology

BAA 09-01 released for Multipath Exploitation Radar

- Develop the algorithms for detection and tracking in high-multipath urban environments

https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-BAA-09-01/listing.html