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Context Enabled Computing

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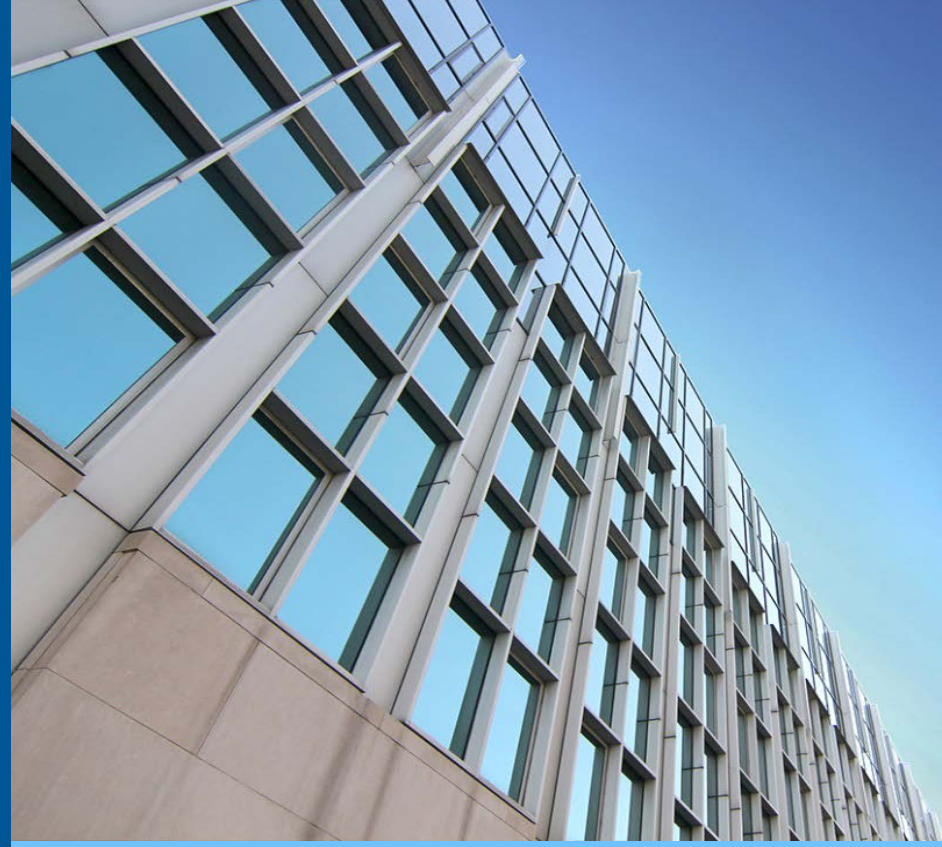


Overview

- Advanced Mobile Systems (AMS) Group Research Areas
- It’s all about Context
- AMS context based computing
- Context use cases and experimentation
  - Benghazi case study (see demo in the hall)
  - Group activity recognition
  - Cooperative and opportunistic context sharing
  - Context in DIL environments

Advanced Mobile Systems (AMS)

Investigates efficient and easily-deployable mobile solutions for teams operating in edge environments. Edge environments are characterized by dynamic context, limited computing resources, high stress, and poor connectivity.

AMS prototypes capabilities for stakeholders operating in mission-critical environments that

- improve situational awareness and data analysis
- reduce cognitive load and complexity by exploiting contextual information
- increase computing power, data access, and survivability while reducing power demands

AMS facilitates interactive mission assistance in edge environments by leveraging available sensors and information from other people and systems.

AMS Research Areas

Tactical Analytics *(TA)*	Application of data analytics to streaming and other data for near real-time analysis and rapid decision cycles in tactical settings
Tactical Computing and Communications *(TCC)*	Strategies for enhanced computing capabilities in environments characterized by limited computational resources and power, and frequently disconnected, intermittent, and low-bandwidth (DIL) communications

Tactical Computing and Communications (TCC)

Information Superiority to the Edge (ISE)	Mobile solutions that reduce cognitive load and conserve resources of individuals and groups by exploiting sensor, role/task, and event information, such that the right information, at the right time, is presented to the right soldier
Tactical Cloudlets	Cyber-foraging solutions that dynamically augment the computing resources of resource-limited mobile devices and address critical system qualities not considered by the commercial mobile ecosystem, such as survivability, resiliency, and trust
Delay Tolerant Networking (DTN)	Applying DTN to disconnected, interrupted, and low-bandwidth (DIL) tactical environments
Geo Intelligence	Obfuscation of queries to commercial GIS databases

Tactical Analytics (TA)

Edge Analytics	End-to-end, near real-time data analysis of static and streaming data for resource-constrained edge environments. Current research is exploring algorithms that quantify credibility of social media
Transfer Learning	Exploration of a type of machine learning called transfer learning applied to the problem of helping junior analysts perform more like experienced analysts in recognizing recurrent patterns, relating new information to these patterns, and recognizing new variants of the pattern
Supervised LDA	Exploration of enhanced use of analyst-provided input to improve the ability of machine learning technology to structure open source data in order to improve the ability of analysts to explore, interact with, and understand the data
Fusion	Strategies to assist analysts in correlating and relating various forms of open source data and intel data from other sources

It’s all about Context

- “Understanding and using context”
  - Anind K. Dey, Personal and Ubiquitous Computing, 2001

“Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.”

- Traditional usage is person, location, and time
  - Example: Cursor on Target (CoT) -- What, Where, When
- Again from Dr. Dey

*“A system is context-aware if it uses context to provide relevant information and/or services to the user, **where relevancy depends on the user’s task**.”*

- Personal and environmental context
- Context is the next battle in mobile
  - Google Now vs. Siri vs. Cortana vs. Amazon Echo vs. ???

Polling Question 1 - Surprise

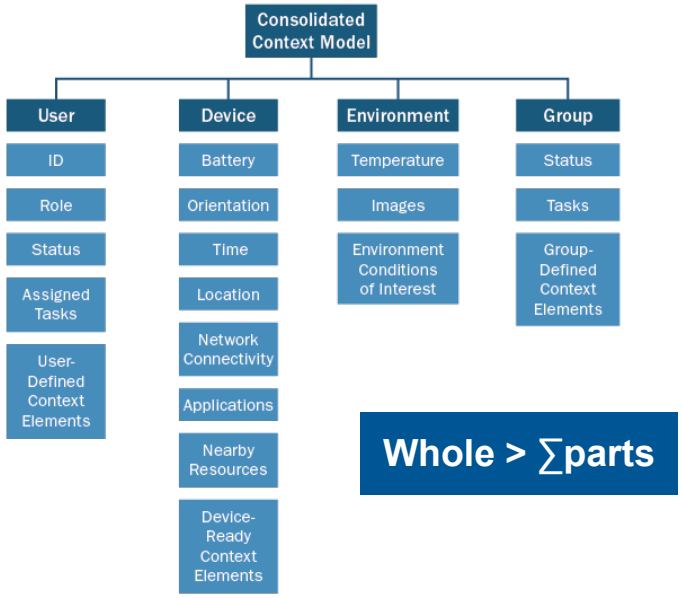
Have you ever been surprised by one of your devices, mobile or otherwise, that it presented information or alerted you based on information it gathered from context?

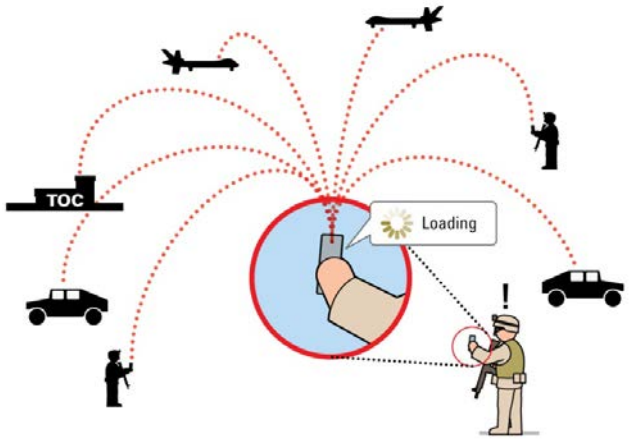
A. Yes
B. No

AMS Context Based Computing

- Expand context to include
  - *User, location, time **and***
  - *Mission, role, task*
- Leverage context across the group
  - First responders and teams of soldiers operate in groups with common mission
- Enable adaptive behavior via rules engine
  - User context cues sensor tasking and information delivery
  - Sensor data cues context changes

Information Superiority to the Edge



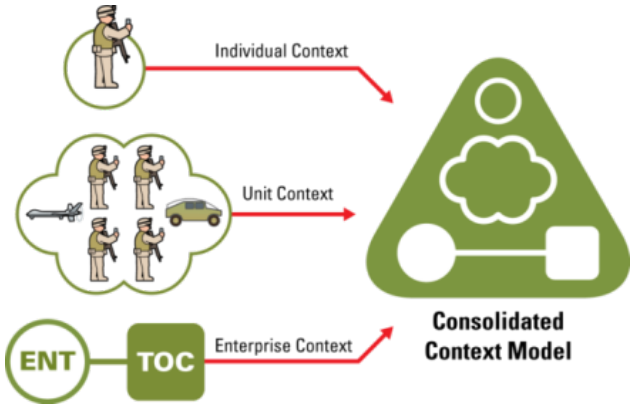


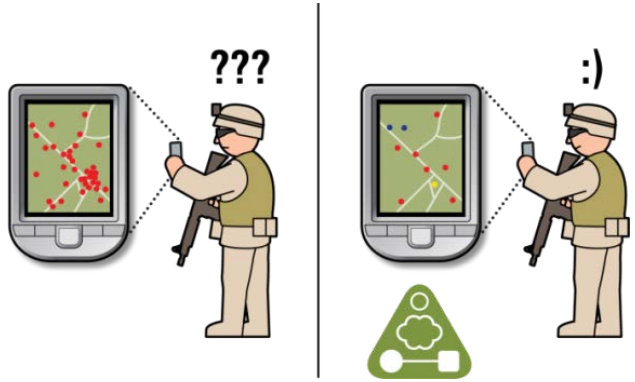
Group context aware reference architecture, middleware, data model, and prototype implementation to reduce cognitive load and conserve resources by using sensor, role/task, and event information to deliver the right information, at the right time, to the right soldier

Context Model: Expand the context model beyond time and location, resulting in broader and more complete understanding

Context Reasoning: Broader context model allows reasoning and reaction to the context of the individual, other individuals, the group, and the organization.

Information Superiority to the Edge



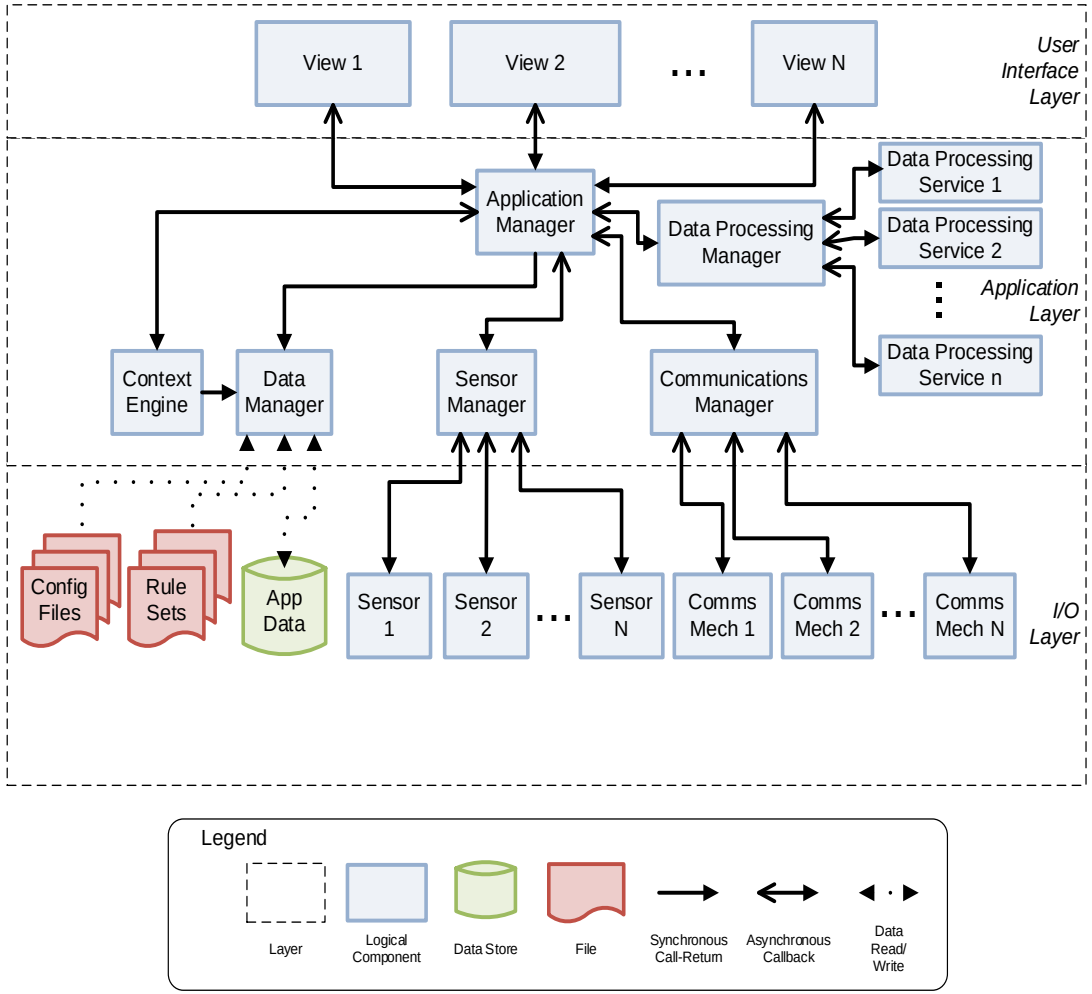


Resource Usage: Use of broader context allows smarter and more efficient resource allocation.

Cognitive Load: Richer context models can decrease the soldier's cognitive load required to capture, visualize and react to situational information.

Research Focus: Leveraging individual and group context to reliably deliver the right information, to the right soldier, at the right time

Reference Architecture for Mobile Applications at the Edge (ISE & DTN)



Key Qualities

- Modifiability
  - the ability to change between the views, rules, configurations, sensors, and radios without significant effort
- Extensibility
  - the ability to integrate new views, sensors, radios, profiles, and rules without impacting the rest of the architecture

Context Use Cases and Experimentation

- Benghazi case study
  - Combination of Edge Analytics (real time social media streaming analysis) and ISE for tactical situational awareness
- Group activity recognition
  - Collaboration with 911 AF Reserve Wing at PAS
- Cooperative and opportunistic context sharing
  - Combine CMU Group Context Framework (opportunistic context)
  - With ISE (cooperative context)
- Context in DIL (Disconnected, Intermittent, Low-bandwidth) environments
  - Metadata extensions to Delay Tolerant Networking (DTN) protocols
  - NACK based UDP protocol for tactical wireless networks

Benghazi Scenario - Background

Request by DoD stakeholders

- Develop prototype from existing technology to demonstrate mobile handheld situational awareness (SA) to aid US personnel in foreign countries

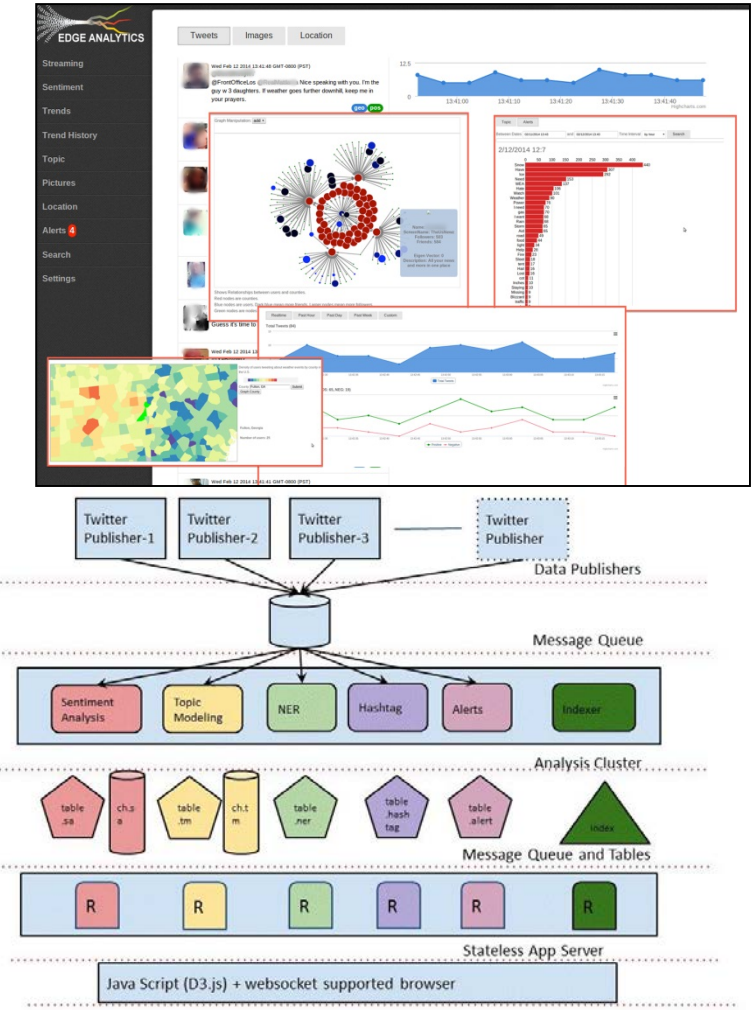
Combine two ongoing research prototypes

- Information Superiority to the Edge (ISE)
  - Group context aware middleware and handheld SA
- Edge Analytics
  - Streaming data analysis to support rapid Intelligence Preparation of the Battlespace (IPB)

Link Open Source Intelligence (OSINT) to mobile Situational Awareness (SA)

Edge Analytics

- Scalable architecture for real time streaming data
- Initially focused on Twitter
  - Extended for arbitrary text input
- Used in numerous field experiments
  - CreationFest 2013 and 2014
  - Little League World Series
  - Wireless Emergency Alert Service
  - MIT LL Next-Generation Incident Command System
- Pluggable analysis engines
- Accessible via web browser



Benghazi Scenario - Background

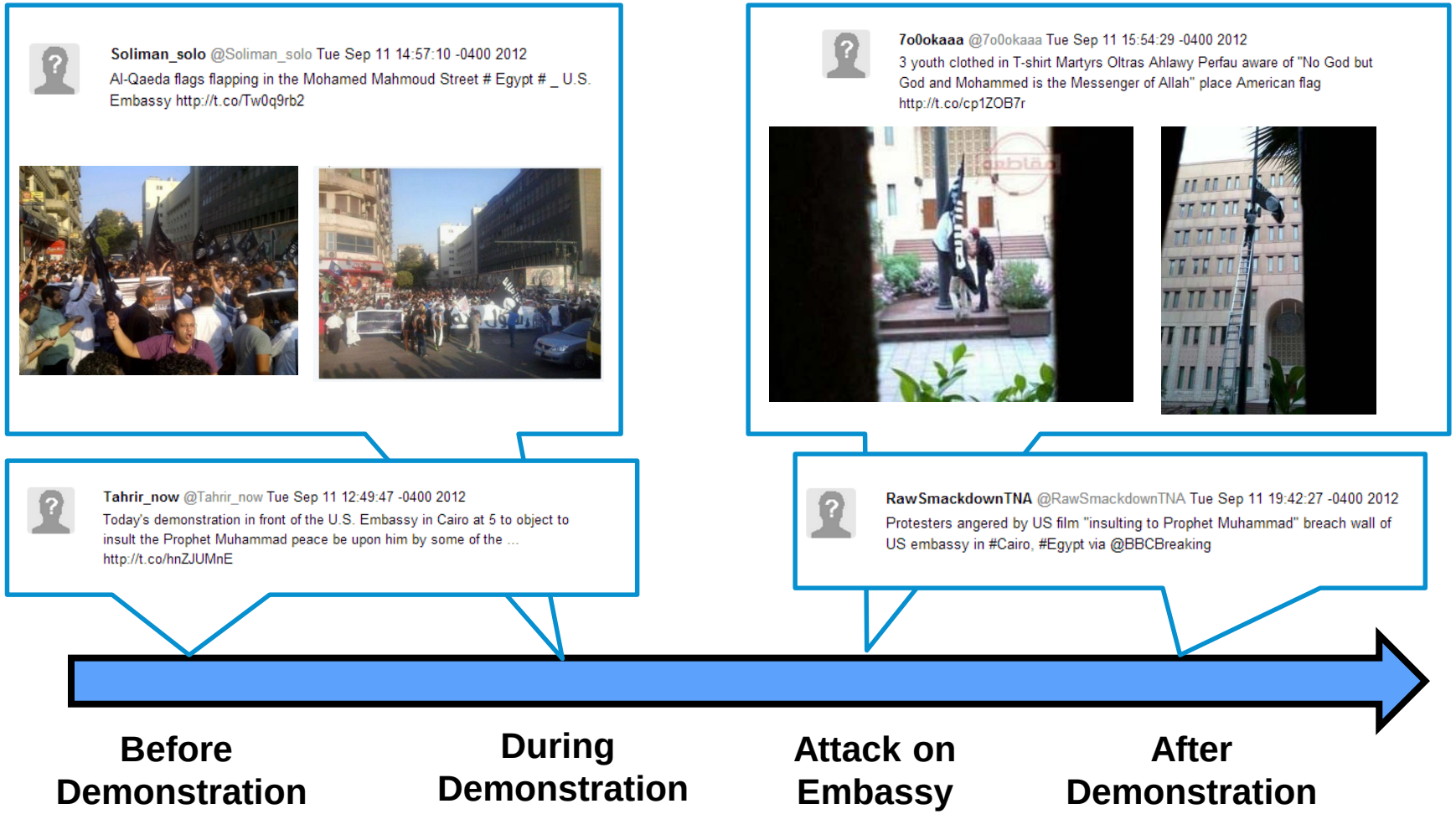
Between September 11 and 17, 2012, diplomatic missions in the Middle East, Asia, and Europe were subject to protests and violent attacks in response to an inflammatory video, *Innocence of Muslims*.

Cairo: Reaction to YouTube Trailer

11 Sep 2012 @ 5pm:
About 3,000 demonstrators assemble outside the American Embassy in Cairo.

About a dozen men scaled the walls and tore down the US flag, replacing it with the black Islamist flag bearing the inscription Shahada (“There is no god but God and Muhammad is the messenger of God.”)

Cairo Demonstration Timeline



Benghazi: Reaction

11 Sep 2012 @ 10:40 pm: Large numbers of armed men shouting "Allahu Akbar" descend on the compound from multiple directions lobbing grenades over the wall followed by automatic weapons fire and RPG's. The assailants are backed by truck-mounted artillery and anti-aircraft machine guns.

Polling Question 2 – Social Media

Can information valuable to law enforcement and defense be obtained by twitter and social media?

A. Yes
B. No

Note

The following participants and events are notional and were created to explore what might have been possible by integrating social media information (OSINT) with traditional intelligence combined with improved mobile situational awareness and communications.

Preparation

- Analyzed over 1.2M tweets from the 2 weeks surrounding the Benghazi and Cairo events
- Geographically centered on Benghazi and Cairo
- Numerous keywords included in search
- Included English (≈60%) and machine translated Arabic tweets (≈40%)
  - Not a perfect translation, but suitable for machine learning algorithmic analysis
- Integrated two existing research prototypes to enable data sharing

Scenario Overview

Several notional people that could have been in Benghazi at the time of the attack

(BT) Business Traveler – a US citizen travelling and operating in Benghazi strictly for business purposes.

(CE) Consulate Employee – a US consulate employee stationed at the diplomatic mission in Benghazi, but not present on the compound at the start of the attack.

(SO) Special Operator – multiple US Special Operations personnel on a variety of missions in Benghazi at the outset of the attack.

(QRF) Quick Reaction Force – the members of the quick reaction force that deployed from the CIA compound near the diplomatic mission after the attack began.

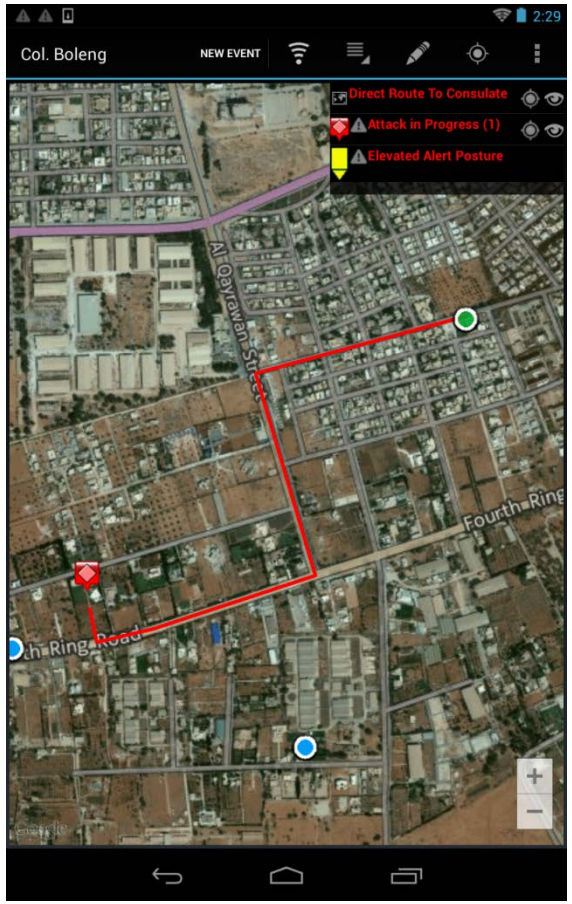
(C2) Command and Control – a command and control element at the CIA compound that would have been monitoring OSINT and other sources of intelligence before the attack and coordinating response and C2 of the various other actors as events unfolded.

Scenario Overview

- Scenario begins by monitoring social media and other channels in the days prior to the release of “Innocence of Muslims” on YouTube (11 Sep 12)
- Large social media activity calling for a demonstration at the US Embassy in Cairo
- (6:00 pm) Data and imagery regarding the Cairo breach are shared with the Benghazi C2 Intel element
- (9:40 pm) Attack on diplomatic mission in Benghazi begins
  - Alarm sounds and is noticed by the C2 element at the CIA Annex
  - Attack in progress message sent to all users on mobile device
  - Rules provide contextually relevant information to each user

Screen shot examples

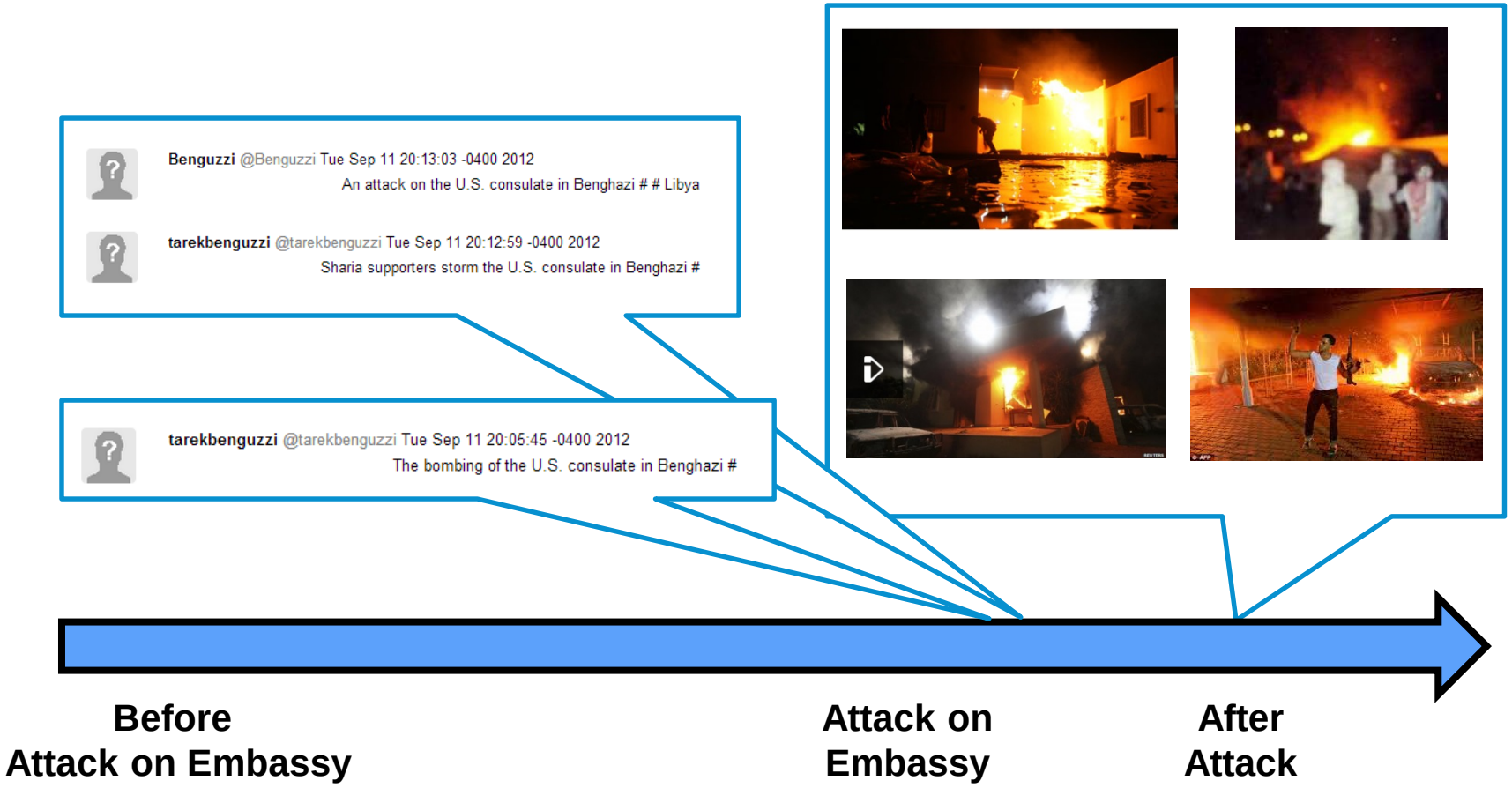
BT is instructed to leave the city, egress routes to airport and bus station avoiding the attack are presented



SO personnel are notified and allowed to respond in support or continue on current mission, routing to attack is presented

Benghazi Timeline

- Tweets and social media artifacts of attack appear 20-25 minutes after the outset
- Annex aware of attack sooner, but not on scene, OSINT shared with them en-route providing valuable intel of emerging situation



Remainder of the scenario

- Scenario continues with SO personnel responding and assisting QRF
- SO provides over watch and intel to QRF before they arrive at consulate
  - Images, video, approach routes, and map annotations all provided
- Consulate employee is routed successfully around roadblock and is extracted by QRF
- Real time location of all personnel appropriately shared based on need to know
- Scenario concludes with coordinated extraction of all personnel via the airport similar to Senate report
- Full scenario details sensitive

Edge Analytics: What we learned from twitter

Cairo

- Demonstration was well planned. Lots of trending social media before hand
- No evidence of embassy wall breach planned in the Cairo tweets
- Breach appears to have been opportunistic but demonstration was well planned

Benghazi

- No evidence of planning for demonstration OR attack in Benghazi – Twitter silent
- About 22 minutes after the attack began Twitter begins to trend
- Initial traditional media reports say that the attack was the result of a demonstration
- Social media totally refutes this
- Lack of strong trending initially from the Benghazi attack can be informative
  - No attempt to rally protesters may hint that it was not and never was a protest
  - Knowing it was not a protest may allow responding forces to operate differently
    - fewer concerns about innocents caught up in attack

Value of OSINT (environmental context)

Forensic Analysis

- apply data mining techniques to historical data

Reactive Intelligence

- provides situational awareness to reacting teams such that they are informed of emerging events and can react to those events

Predictive Intelligent

- that allows reacting teams to prepare for an event that has a relatively high likelihood of occurring

Preventative Intelligence

- that allows reacting teams to head off certain events by providing information that reduces the likelihood of these events

Additional Findings

- Machine Language Translation (MLT) of foreign languages is sufficient for many uses
- Contextual delivery of information by role and task (profile) is effective
  - Reduces information clutter and cognitive load
  - Facilitates information sharing and timeliness
- Real time analysis of streaming data
  - Not appropriate to find the “needle in the haystack”
    - Might be possible during forensic analysis
  - Patterns and signatures of events stand out
  - Sophisticated adversaries do not use social media
  - However, field experiments show significant events that can threaten public safety trend on twitter **before** they occur

Polling Question 3 – Context in your mission

Would a cloud based context analysis engine, coupled with personal context on a mobile device, be beneficial in your problem sets or aid your mission?

A. Yes
B. No

Group context recognition

- Required a scenario with realistic feedback → paintball
- 20+ volunteers from 911th Air Reserve Wing
- Small squad tactics as scenarios
- 7 group activities, 10 individual activities, 3 IMU's and phone per person

Group activity results

- Multiple Gigabytes of video data – challenging to annotate
- 5 types of classifier: SVM, decision tree, kNN, naïve bayes, neural network (# of hidden=10)
- Best combination of sensors: Phone (acc) + YEI arm sensor + YEI leg sensor
- 81% accuracy of individual activity recognition (SVM)
  - Shooting, covering, running, etc.
- 71% accuracy on group activity recognition (kNN and Neural Net)
  - Advance, covered advance, covering fire, etc.

Polling Question 4 – Use of Machine Learning

Do you use Machine Learning in your research or operational systems?

A. Yes – in operational systems
B. Yes – in research only
C. Yes – in research and operational systems
D. No

Cooperative and Opportunistic Context

- Experimentation at large music festival in PA
- Provided “assistance application” to festival volunteers
- Opportunistic Context → CMU Group Context Framework
  - http://ubicomplab.org/publications/the-group-context-framework-an-extensible-toolkit-for-opportunistic-grouping-and-collaboration/
  - Work of Adrian de Freitas and Dr. Anind Dey at CMU
- Cooperative Context – ISE
- Fuse and visualize data via MQTT message broker and web front end
- Scenarios
  - Location tracking
  - Bluetooth location
  - Noise localization
  - Lost person location
  - Cueing sensors from social media events (Edge Analytics)

Polling Question 5 – Context and Privacy

How significant is the use of context to privacy?

A. Very significant
B. Significant
C. Moderately significant
D. Somewhat significant
E. Not significant at all

Context in Tactical Wireless Networks

- Tactical Wireless Networks
  - DIL – Disconnected, Intermittent, Low-bandwidth
- Three broad approaches researched to increase performance

- **Application Layer** – use context to ensure the right information is delivered to the right people (device) at the right time (ISE)

- **Network Layer** – Delay Tolerant Networking and Link Awareness to ensure bandwidth is used most effectively

- **Link Layer** – NACK based UDP (vice TCP) to overcome wireless fading and the intermittent nature of tactical wireless networks

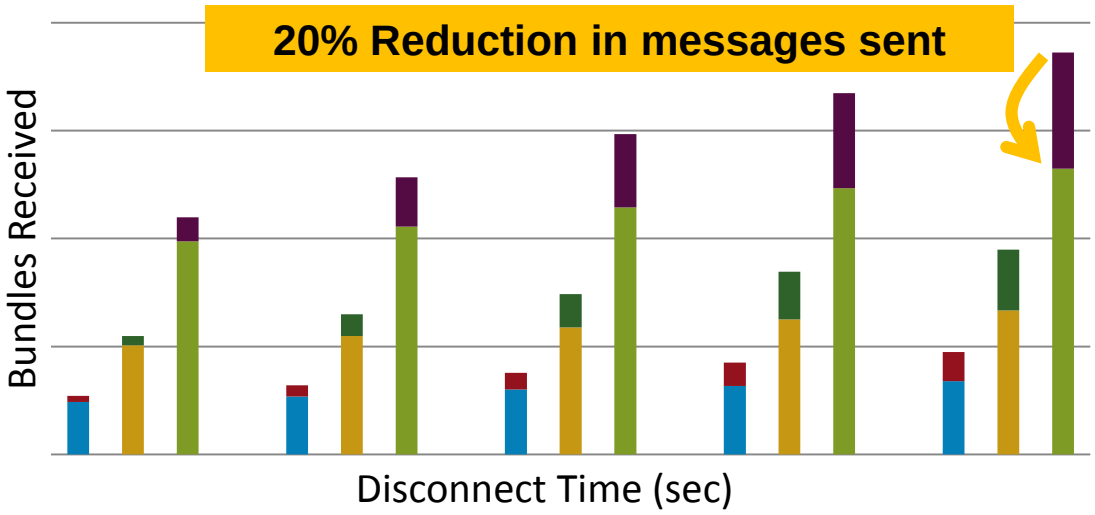
Context for Delay Tolerant Networking

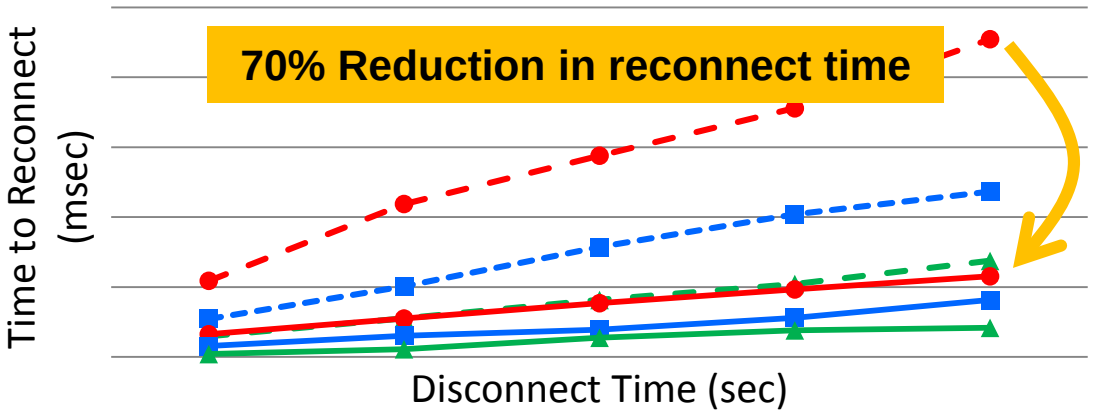
Maintain shared group context Make best use of available bandwidth	Applications continue to function Predict state where possible	Re-establish shared group context as quickly and accurately as possible
Pre-cache data likely to be relevant later in the mission	Predict location of teams based on mission plan	Prioritize synchronization of critical messages • data staleness • data updates • redundancy elimination • conditional delivery
Delay transmission of noncritical data	Provide connectivity map to help the user reconnect	

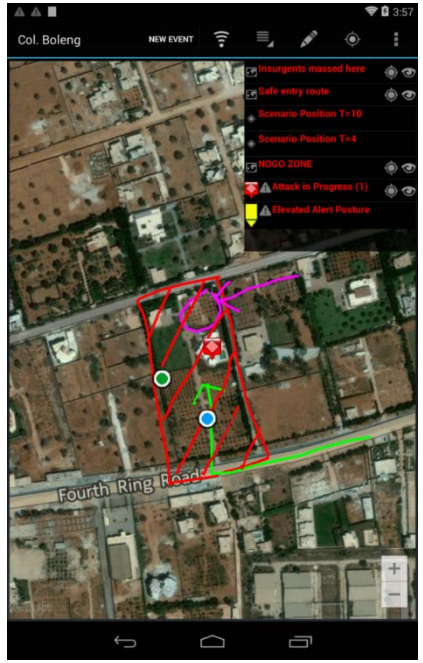
Solutions that support warfighter networking in Disconnected, Interrupted, and Low-bandwidth (DIL) environments

Enhancements to existing networking protocols for managing these environments, significantly improving performance WRT to bandwidth usage and synchronization time

Delay Tolerant Networking with context – initial results







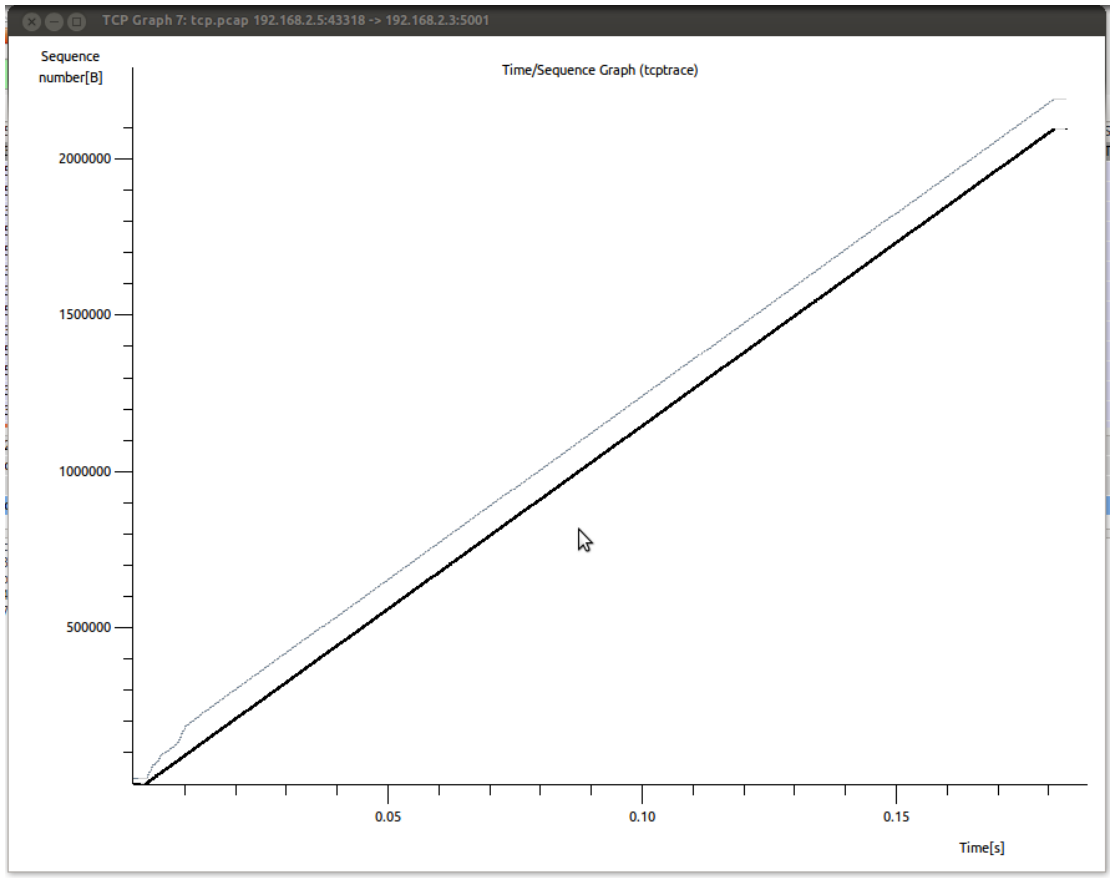
DTN Results – field testing with AN-PRC-117G

- No DTN
  - 30 total file/event transfers (approx. 12.3MB)
  - 12 event and 9 file transfer failures (approx. 9.2MB)
  - 98 seconds to transfer all data
  - 75% of the network bandwidth used for retransmissions
- Basic DTN (store-carry-forward)
  - Same transfer scenario
  - 25% bandwidth savings over no DTN
  - 73 seconds to transfer all data
  - Still approx. 66% of bandwidth used for retransmissions
- DTN with context (via metadata extension headers)
  - 66% bandwidth savings over DTN
  - 75% bandwidth savings over non-DTN
  - 24 seconds to transfer all data

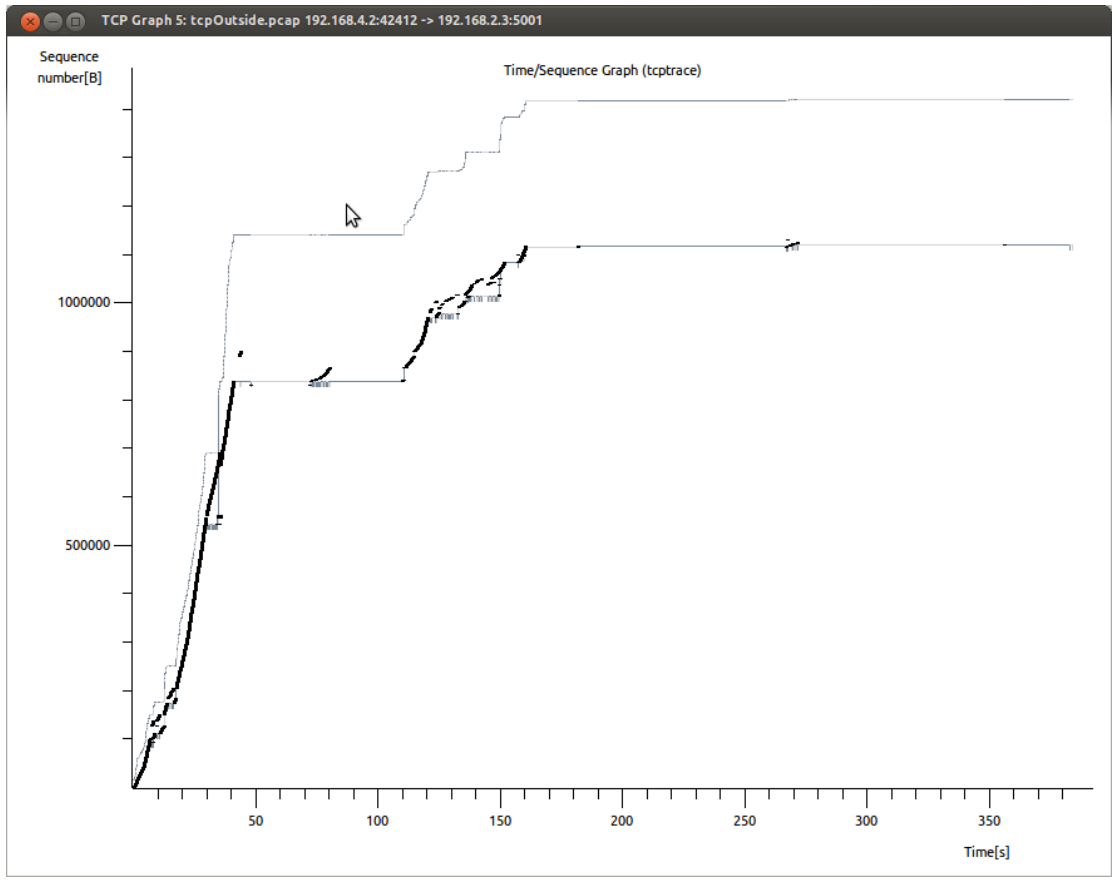
NACK based UDP

- Experimentation with recently procured tactical radios (AN-PRC-117G)
- Two radios transmitting data representative of traditional Intelligence products
  - Events and notifications
  - C2, SITREPS and OPREPS
  - Location (e.g. Blue Force Tracking)
  - Imagery and video
- Custom NACK based UDP protocol developed
  - Inspired by Naval Research Labs NORM (NACK Oriented Reliable Multicast)
  - All stations beacon last sent segment
  - Selective request and retransmission of missed segments
  - Beacons provide continuous link awareness and availability

TCP Performance – Wired vs. Wireless



Wired



Wireless

NACK based UPD Results – field testing with AN-PRC-117G

- Numerous baseline tests
  - Packet generation rates of 500Kbps to 10Mbps (500Kbps, 1, 2, 4, 6, 8, 10Mbps)
  - Datagram sizes of 1KB to 64 KB (1, 2, 4, 8, 16, 32, 64KB)
  - Datagram sizes smaller than one MTU 100B to 1400B at 100B intervals
  - TCP window size variations from 5KB to 500KB
- UDP performance
  - 1.98Mbps with packets under 1 MTU
  - Successful transmission of packets up to 16KB in size
  - 1-1.2Mbps for very small MTU (100-300B)
  - 1.97-1.98Mbps for MTU sizes 400-1470B
- TCP performance
  - RTT of 700ms
  - TCP window size of 170KB optimal with bandwidth delay product
  - Experimentation confirmed 100-200KB window size is optimal for this RTT

NACK based UDP Protocol Tuning

- Tuning parameters
  - Packet size
  - Batch size
  - Sleep time between packet batches
- Radio separation
  - Vary distance
  - Vary LOS visibility