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RPPR Final Report
as of 11-Jun-2018

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Proposal Number: 68590NSRIP **Agreement Number: W911NF-16-1-0226**
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STEM Degrees: 0 **STEM Participants:** 3

Major Goals: One key limitation of the current mobile communication systems used by the U.S. Army is the lack of adaptability. These systems operate based on the fixed communication strategies that are configured during the tactical mission planning. It is difficult for them to autonomously maintain warfighters' situational awareness over heterogeneous battlefield contexts, due to their deficiency of recognizing these contexts and adapting to the corresponding warfighter behaviors such as squad reformation.

The major factor hindering such adaptability is the practical Disconnected, Intermittent, and Limited (DIL) network environment at the tactical edge, where end-to-end network connectivity is usually unavailable. Instead, environmental dynamics and warfighter mobility lead to opportunistic and intermittent network disconnection, and warfighters only communicate when they move into the communication range of others' wireless radios, referred to as contact.

Therefore, a solution to adaptive mobile networking in tactical DIL network environments is urgent. The PI envisions that such adaptability could be achieved based on properly articulated multi-genre network analysis, which exploits the close coupling between mobile communication networks and human social networks at the tactical edge to allow autonomous characterization of warfighters' social dynamics from their contact patterns without manual inputs or configurations. Built on this vision, the PI is funded by ARO to develop sociological metrics and adaptive mobile networking paradigms for efficient mobile communication in tactical DIL network environments.

However, the methods being used to evaluate the performance of the proposed networking paradigms, protocols and techniques in the PI's research have been limited to trace-driven simulation, which are ineffective in emulating the various practical wireless network characteristics, especially in the PHY and MAC layers, at the tactical edge. Therefore, the focus of this DURIP project is to augment the PI's capability of mobile networking experimentation and system evaluation, by acquiring a set of software-defined radio (SDR) and corresponding measurement equipments. More specifically, these equipments include the WARP (Wireless Open-Access Research Platform) SDR platforms, a high-resolution digital oscilloscope and a digital spectrum analyzer. This acquisition allows development of a fully functional wireless network testbed that is able to emulate heterogeneous wireless network characteristics in tactical DIL environments, as well as their impacts on the wireless communication channels. Built on the acquired equipments, the PI also plans to conduct detailed experiments to investigate the impacts of these wireless network dynamics, environmental factors and human behavior patterns on the performance of the proposed tactical mobile networking schemes.

Accomplishments: Built on the purchased equipments of this DURIP grant, we have been extensively working on

incorporating the prior tactical knowledge into the process of predicting warfighters' contacts with each other and hence improving the accuracy of such prediction, and the result of this research has been published at the Proceedings of Military Communication Conference (MILCOM), 2016. This work focuses on eliminating the gap between the contact patterns of warfighters and their social relationship, which is the key factor that impairs the accuracy of contact prediction among these warfighters at the tactical edge. Initially, warfighters' social relationship with each other is decided during tactical mission planning before deployment, in the form of tactical squads or special mission teams. Such relationship is hence fixed and independent from their behaviors in theater. However, after deployment, their social relationship will dynamically change according to the situational battlefield contexts, being reflected by their contact patterns. Existing techniques characterize such social relationship by inferring social structures from warfighters' contact patterns, but ignore the impact of the prior tactical knowledge of such social relationship before deployment. Such ignorance, obviously, impairs the accuracy of contact prediction at the tactical edge and further reduces the performance of mobile communication among warfighters.

To bridge this gap, we proposed a probabilistic contact prediction framework that combines both deployment information about the initial social relationship among warfighters and the contact patterns of warfighters after deployment. The basic technical approach is to employ Bayesian inference, and investigate both models in the temporal domain to reflect the temporal evolutions of the social relationship and contact patterns of warfighters over time. Our framework quantitatively models the temporal evolution of the impact of the warfighters' deployment information on their social relationship over time. This framework has been implemented and evaluated over the WARP v3 SDR platforms purchased by the DURIP grant, and experiment results demonstrated that it significantly improves the accuracy of contact prediction at tactical network scenarios.

Built on this framework, we have been further working on developing systematic emulation framework that integrates functionality of opportunistic mobile networking in the DIL environment into the Extendable Mobile Ad-hoc Network Emulator (EMANE), which was developed by the U.S. Naval Research Laboratory over the ns-3 platform and serves as one of the most popular military network emulators nowadays. More specifically, we exploit the existing link-state-based routing mechanism in EMANE as much as possible, and insert new carry-and-forward routing mechanisms as plugin to the existing OLSRD protocols. Such new routing mechanisms are then integrated with our new mobility script generator to emulate practical DIL network environments with diverse network connectivity and contact patterns. They also allow flexible insertion of various social-aware metrics for relay selection, and hence enable emulating a wide collection of practical carry-and-forward routing mechanisms.

In particular, we have also integrated such EMANE emulations with the WARP v3 SDR toolkits, so as to introduce realistic wireless PHY characteristics into the emulation process. To do this, we utilize the WARPLab software toolkits provided by the WARP manufacturer, as a suite of Matlab libraries, to direct the analog outputs from the RF antennas to the built-in PHY-layer modules of EMANE, and further utilize such PHY-layer signals to instruct the MAC-layer operations. The preliminary experimentation results have demonstrated that such implementation could be efficiently executed over ordinary PCs with satisfiable performance and low amounts of system resource consumption. This work has been submitted to the 2018 Military Communication Conference (MILCOM).

Furthermore, we have also developed novel wireless network scheduling algorithms that coordinate multiple warfighters' behaviors to ensure precise prediction of their future contacts and efficient characterization of their social relationship. More specifically, when the network link conditions change due to various network dynamics, instead of frequently rescheduling the entire wireless network regardless of the specific network dynamics, our work exploits the locality of the impact of network dynamics, and hence develops distributed algorithms that adaptively constrain network scheduling within the limited scope where network dynamics occur. In this way, we are able to significantly reduce the high volumes of computation and communication overhead caused by frequent network rescheduling at the global scope, without affecting the wireless network performance. The performance of our proposed algorithms has been validated by formal analysis, and also been verified by our implementation over the WARP testbeds. This work has been published at IEEE Conference on Network Protocols (ICNP) in 2016.

Training Opportunities: The software-defined radio equipments purchased from this DURIP grant have provided many opportunities to undergraduate and graduate students at University of Tennessee, Knoxville, by allowing them to practice their hands-on skills of building custom wireless systems at the PHY and MAC layers. In particular, these equipments helped involve minority and underrepresented groups of students into research through the REU programs at UTK, and hence prepared workforces for our nation.

Results Dissemination: The equipments purchased from this DURIP grant have resulted in several research papers published at top-tier journals and conference proceedings. They also resulted in open-sourced software packages for military-grade large-scale network emulation and testing.

Honors and Awards: 1) Chancellor's Award for Professional Promise in Research and Creative Achievement, University of Tennessee, 4/2017.

2) Chancellor's Award for Extraordinary Professional Promise, as the graduate advisor of Ph.D. students Haoyang Lu and Yong Li, University of Tennessee, 4/2017.

3) Outstanding Researcher, College of Engineering, University of Tennessee, 9/2016.

4) Professional Promise in Research Award, College of Engineering, University of Tennessee, 4/2016.

Protocol Activity Status:

Technology Transfer: The PI is actively working with the Space and Terrestrial Communications (S & TCD) Directorate of Army CERDEC, to translate the developed software packages for EMANE into active use of tactical network emulation and evaluation.

PARTICIPANTS:

Participant Type: PD/PI
Participant: Wei Gao
Person Months Worked: 3.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Participant: Yu Zhao
Person Months Worked: 6.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Yong Li
Person Months Worked: 3.00 **Funding Support:**
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International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Haoyang Lu
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
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International Travel:

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National Academy Member: N
Other Collaborators:

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Paper Title: Exploiting deployment information for social-aware contact prediction at the tactical edge
Authors: Wei Gao
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2016 IEEE 24th International Conference on Network Protocols (ICNP)
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Paper Title: Scheduling dynamic wireless networks with limited operations
Authors: Haoyang Lu and Wei Gao
Acknowledged Federal Support: **Y**

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Paper Title: Continuous Wireless Link Rates for Internet of Things
Authors: Haoyang Lu and Wei Gao
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Paper Title: A Tactical Emulator for Opportunistic Mobile Networking
Authors: Yu Zhao and Wei Gao
Acknowledged Federal Support: **Y**

Nothing to report in the uploaded pdf (see accomplishments).