White Paper: Response to NITRD RFI on the Five-Year Strategic Plan for the Federal NITRD Program

Our vision for the NITRD program revolves around four major thrusts, namely network science, evolvable networking architectures, innovative networking paradigms and cyber security. Next, we discuss the thrusts in the context of the two questions posed by the RFI:

- ***What do you imagine as the future in terms of desired NIT capabilities?***

Establishing a new field of network science is of paramount importance to the society which depends on a diversity of complex networks, e.g. transportation, biological, social, military. It is a multi-disciplinary area that requires multiple agencies joining forces to coordinate incoherent research investments and identify dualities and common concepts across domains. The objective is to develop rigorous mathematical basis and measurement tools to model, at sufficient fidelity and with sufficient scale, design, analyze, predict and control the behavior of networked entities.

The emergence of diverse networking applications, e.g. embedded networked systems, automation, networked rovers, and delay-tolerant applications, clearly demonstrates that a manually-configured static networking stack (e.g. TCP/IP) cannot fit all. An efficient and effective substitute for stove-piped systems is to build *evolvable networking software* that can evolve to synthesize, at run-time, the optimal networking architecture and seamlessly morph across stacks to match the diverse objectives and constraints of vastly different applications.

Geo-Networking (GeoNET) is a strong candidate for *networking paradigms beyond IP* due to optimally exploiting location information to simplify routing, address translation and mobility management. Furthermore, GeoNET capitalizes on location-based services projected to dominate over the coming decade. This requires new approaches to geo-based addressing, geo-MAC for interference avoidance, geo-routing, geo-based constructs, e.g. geo-cast and geo-gather.

Rate/Reliability/Latency Network Utility Maximization (R/R/L NUM) extends rate-based NUM to dynamically balance the fundamental rate-reliability-latency trade-off in wireless networks. It is a key enabler of clean-slate networking architectures, founded on network and information theory formulations. This requires mathematical tools to develop an overarching NUM formulation, dynamic multi-objective utility functions, and optimization decompositions.

Finally, cyber security is not merely about security, its more about *Self-resilient Trustworthy systems* where new models, logics, and theories for analyzing and reasoning about security, reliability, privacy and usability come into play. Cyber security is an inherently multi-disciplinary area where technology, policy and business need to converge to support foundational research.

- ***What roles do you imagine for the NITRD Program and for the academic, commercial, international, and other domains in achieving that future?***

The NITRD program should foster fundamental and applied research through creating programs along one, or more, of the four areas identified above. Academics should lead the network science and R/R/L NUM initiatives with strong support form the industry to apply developed theories and feedback their insights. Both academia and industry should co-lead the cyber security initiative due to its complex nature that goes beyond technology to policy and business aspects that need strong industry involvement. The evolvable networking architecture and GeoNET initiatives would also require strong partnership between industry and academia due to their systems focus. The international community should streamline the process of know-how dissemination, information sharing across borders through multi-disciplinary conferences, committees and student exchange.

Next, we address the following six challenges highlighted in the RFI:

- ***Development and execution of multi-agency and multi-disciplinary programs***

Network Science Program: NSF-NIH-DARPA-DOD-DOE/SC.
Evolvable Networking Architecture Program: NASA-DARPA-DOD-NSF.
GeoNET Program: NASA-DHS-DARPA-DOD-NIST-NSF.
R/R/L NUM Program: NSF-DARPA-DOD-DOE.
Cyber security and Information Assurance Program: DHS-NIST-NSA-NSF-DARPA.

Form a core multi-disciplinary team that manages and coordinates the work of multiple sub-teams, each focused on a subset of disciplines with highest synergy.

- ***Determination of strategic goals, key challenges, opportunities, and research priorities***

Strategic Goals: National security, prosperity and welfare of the people, US IT leadership, Information and Decision superiority, US energy independence, and US dominance in space.
Key Challenges: collaboration, communication and reaching the best abstractions (APIs) across disciplines, bridging the gap between theory and practice, optimal transition milestones, unconventional & innovative types of cyberattacks, and diverse types of distributed applications.
Opportunities: capitalize on H/W trends attributed to Moore's law, advances in sensing, MEMS and embedded systems, plethora of emerging wireless technologies, strong market pull for new applications, convergence of control, comm. and computing, and seeds for network theory.
Research priorities: *Theory:* highest priority is R/R/L NUM followed by long-term network science and cyber security. *Systems:* highest priority is evolvable networking architectures, followed by GeoNET and cyber security.

- ***Examples that illustrate the impact of realizing the vision, achieving the proposed goals, and meeting the identified challenges***

Establishing the new field of network science should lead to new findings and theories with direct impact on operating transportation, financial and communication networks as well as better understanding the immensely complex biological and social networks.

Availability of evolvable networking architectures significantly reduces the resources needed to build a "tailored" networking infrastructure for diverse applications that exist nowadays or will emerge sometime in the future. This will surely have a significant societal and economic positive impact due to deploying cost-effective services for the public much faster.

GeoNET simplifies packet routing, enables scalable networked systems, e.g. border control, facilitates NASA exploration and science missions, enables next generation GIG and DHS pre-dominantly location-based applications.

Successful deployment of a reliable cyber security infrastructure facilitates and streamlines the process of information sharing among trusted parties for civilian applications, with prevalent impact on the global economy (e.g. e-commerce), as well as national security.

- ***Transition of R&D results into practice***

Leverage COTS technologies, as much as possible, shortens the transition path and strengthens risk mitigation. Maintain close collaboration among government, industry and academia in multi-phase programs. Promote proof-of-concept prototypes and demonstrations early-on in the program serves dual-role: proves/disproves the soundness of theory and underlying assumptions early-on and provides key insights to basic research about challenges and limitations.

- ***Role of the U.S. in the international NIT arena***

As it has always been, the US should lead NIT innovations encouraging the international partners to plan an aggressive R&D portfolio, share research findings and exchange experiences.

- ***Interactions among government, commercial, academic, and international sectors***

Industry should work closely with academics to define problems and mature their research to sub-system and prototype levels. The US government agencies need to coordinate with international counterparts in order to layout a coherent R&D portfolio that is effective and efficient.