| 1) Proposed Research Focus: | Broadband Wireless Access and Secure Sensing (BWISSE) | | | | |
|---|---|---|---|---|---|
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## 4) Intellectual Merit:

***A. Need:*** In this day and age, Broadband Wireless Access and Secure Sensing (BWISSE) is a critical need for a vibrant and globally competitive economy. The demand for high-speed broadband with low latency has been exponentially growing in the past decade, moving from text-based internet and email communications to multimedia video-rich environments. Yet the current trend in wireless research is motivated by high demand in dense urban areas, with minimal to no attention given to sparsely populated rural areas covering over 80% of the continental US. Maine's economy heavily relies on tourism and forestry, industry, and small businesses, all in urgent need of affordable broadband with higher speeds. The fiber optic backbone is already in place, but we are missing the last mile connectivity. In addition to day-to-day activities that widespread broadband would facilitate, secure sensor networks can use the idle spectrum to monitor a myriad of other domains, such as monitoring forest health (changes in carbon sequestration rates), detecting wildfires, assisting in securing borders, and even enabling vehicle-to-infrastructure communication to prevent accidents. Integration of these two technologies, broadband wireless access and secure sensing, is the key motivation of the proposed research. The proposed wireless research and development activities in this project addresses sparsely-populated Maine, with its challenging hilly and forested terrain and a long coastline. As one of only five states in the nation with both terrestrial and maritime (borders and ports) security interests, Maine is uniquely positioned to serve as a testbed for broadband access and secure networking research. This NSF investment also positions Maine to become a national leader in rural broadband by creating a public-private partnership.

***B. Research Goal & Objectives:*** The main goal of this research proposal is to develop new paradigms for expanding wireless access in sparsely populated rural areas with challenging environments that have largely been ignored to this point. Hilly terrain, year-round forest foliage changes, and extreme temperature variations combined with snowy winters and humid summers, make Maine the most challenging environment for creating a reliable broadband wireless network that can dynamically change according to channel conditions. The proposed research objectives to address these challenges are: (a) Radiowave propagation research and modeling for rural environments and close-to-ground sensor antennas; (b) Wireless access systems in support of tourism, border/port security, and aging populations; (c) Wireless sensor networks in support of natural resources monitoring (forestry, agriculture, aquaculture). The following interrelated research questions will be investigated:

1. How do wireless signals propagate when antennas are close to the ground or close to the forest canopy?
2. What is the optimum strategy for dynamically changing transmission parameters based on foliage changes (slow change) and weather changes (fast change) to maintain reliable communication link in rural areas?
3. How do current network security procedures scale up in rural areas with larger cells and lower signal levels?
4. What is the optimum trade-off between distributed computing (less communication) and centralized computing (more communication) under various boundary conditions in the network?
5. How accurate are current sensing and prediction models and how can the proposed sensing approach in this project enhance the ability of these models to quantify key processes, such as forest carbon dynamics or aging?
6. Does the hybrid heterogeneous network support cybersecurity elements (e.g., secure communication protocols and services) and maintain cybersecurity resiliency under various demand conditions? (e.g., number of users, throughput requirements, and latency)

***C. Research Actions:***

| Questions | Main Research Goals | Objectives | Research Actions |
|---|---|---|---|
| 1 | Modeling close to ground signal propagation | a, b | **Research action-1:** development of radiowave propagation models for forested areas verified by experimental measurements and refined in several iterations. |
| 2 | Dynamic transmission strategy selection | b, c | **Research action-2:** research and development activities on devices that can withstand extreme environments while providing consistent performance over a large bandwidth. |
| 3 | Network security scalability study | a, b, c | **Research action-3:** research on network security and scalability as the number of users and demand is increased, and developing a new framework to integrate wireless access and sensing into one secure network. |
| 4 | Exploring trade-offs between computing and communications | a, b, c | **Research action-4:** research on computational algorithm suitable for distributed and decentralized implementation to reduce the communication needs and eliminate the requirements for a central processing facility. |
| 5 | Developing accurate forest research and change prediction models | a, c | **Research action-5:** collaborating with forestry and aging initiative researchers and industry end-users to determine projected bandwidth requirements for sensor networks and developing new models for near ground radios indoors and outdoors. |
| 6 | Cyber security resiliency under different demand conditions | a, b, c | **Research action-6:** research potential for confounding effects on cybersecurity resiliency imposed by hybrid heterogeneous network design and implementation. |

***D. Priority:*** In NSF's FY2022 budget request to the congress, broadband and in particular rural broadband has been emphasized as key area for future support. Pandemic readiness, climate sciences, and national security topics are emphasized in White House 2021 R&D Priorities, all in dire need of wide spread broadband wireless to ensure digital equity. Maine 2020-2029 economic development strategy cites broadband affordability and lack of this important utility in large part of Maine. BWISSE project addresses these national/state priorities by developing novel low cost technologies and enabling private industries to invest in Maine.

## 5) Broader Impacts:

***A. In-state collaborations****:* Global competitiveness for various Maine industries, including forestry, agriculture, fisheries, millwork, and healthcare heavily relies on availability of broadband access for marketing, processing orders, and efficient use of sensors for monitoring patients in homes or older individuals in retirement homes. The importance and urgency of such needs have been documented during meetings of the proposal team with local industry. Economic impact of the investment in broadband wireless and sensing is twofold. First, this investment enhances the operation efficiency of existing businesses by boosting their connection speed. Second, it enables offering competitive broadband service that can attract new businesses to Maine and create new jobs, which can drastically change the state's economic landscape. The total economic impact of forest products industry in 2016 is estimated at $8.5 billion while supporting 33,538 jobs in Maine. According to a recent report[1] by the State's ConnectME Authority, the economic impact of broadband on the Maine economy over the coming decade would be to add 11,000 jobs, create $500 million in new income, and pass along $70 million new dollars a year to state and local governments. Two examples that illustrate the impact of the BWISSE project includes assisted living in smart homes for Maine's aging population and creation of infrastructure sensors for driverless cars to operate safely in snow-covered roads. The resulting savings in healthcare costs for the state and the number of jobs created for design and maintenance of these devices will be significant.

***B. Regional/national collaborations****:* Partnership with Northeastern University (Roux Inst., Portland, ME) will provide an opportunity to contribute to digital health programs at this institute, while expanding UMaine's access to NU's network of researchers worldwide. Through a previous NSF EPSCoR Track 2 program, we have been working with UNH and UVM researchers in the area of forest ecosystem monitoring using wireless sensors (2019-2023). This collaboration can be further expanded in this Track 1 project to augment the multiple local networks developed with the larger wide area networking research in this project. A healthy forest for instance can also impact the tourism industry.

***C. Economic development****:* The three research objectives (a,b,c) will each have an associated economic impact assessment as well as individual level economic assessments of core components. These are described below: (a) The problems of rural economic development are well noted but one of the primary constraints to development has been digital infrastructure. An index of rurality will be constructed for Maine. This work will include a digital infrastructure parameter and will estimate current provision and economic output. This will be developed across the life of the project to show how the economic development potential changes as a result of the project. (Online website home of the index, 2 technical reports and 2 journal papers). (b) Tourism remains one of the largest industries in Maine with nearly 12 million people

[1] http://maine.gov/connectme/about/docs/taskforce/broadbandreportsummary.pdf

visiting annually. Work from the World Travel and Tourism Council[2] found that digital infrastructure is critical and key to growing this sector. Using the EIO table constructed in the project, a unique analysis of Maine tourism will focus on spatial economic flows of tourists and the associated monetary injections. This will be achieved by combining EIO and county business pattern data. (2 technical reports and 2 Journal papers). (c) Production analysis of the Forestry, Agriculture, Aquaculture, Border Security will be conducted in a combined report focusing on capital transformation and knowledge. The study will be academically unique in modifying production functions across the life of the project. This real-time dynamic allows productivity changes to be captured much earlier than previous work has done. This will allow the economic impact of BWISSE to be modified or augmented during the process. (2 technical reports & 2 journal papers).

***D. Workforce Development**:* This EPSCoR proposal will attract top graduate students, postdocs and faculty to Maine due to the unique physical infrastructure investment in this area and the availability of a statewide test-bed for novel research in forestry, aging, and transportation. Students trained in this area will be feeding the workforce pipeline, while getting trained at UMaine and via participating in industry internship programs. Mentoring programs and focusing on recruiting a diversified workforce are some of the objectives of our proposed workforce development efforts.

**Undergraduate Students** will be attracted to the program through a mechanism similar to the NSF-REU program, where we actively advertise and recruit undergraduate students from different institutions in Maine and across the country for a 10-week summer research experience program. The Center for Undergraduate Research on the UMaine campus provides supports for this program through its current links and programs developed specifically for undergraduate students. In addition to research programs offered on various sites within the senior personnels' institutions, internship opportunities will be provided by our industry partners to effectively prepare students for the future workforce needs. **Graduate Students** will be mentored by multiple faculty depending on their research program and will work within interdisciplinary teams with focus on problems rather than a specific disciplinary area. They will also gain mentoring experience of their own through mentoring undergraduate students who work alongside them in the lab. We will hold monthly seminars for graduate students to present their research progress to their peers through the academic year and to prepare for their conference presentations. Graduate students will also be provided with industry and federal laboratory internships to augment their academic research and education. **Mentoring Junior Faculty and Postdocs** by senior faculty on a one-on-one basis will be at the core of this project. In addition, professional development workshops offered by various centers at senior personnels' institutions will be offered to provide another layer of professional development. Some examples include workshops on responsible conduct of research, mentoring undergraduate students, and grant writing offered by the center for undergraduate research. Junior faculty and postdocs will play a key role in mentoring graduate students as well as undergraduate students and will gain more experience along the way. **Industry Partnerships** is a unique feature of this proposal with its close connection with industry (Axiom, Pioneer Wireless, Dielectric, Tyler Tech, Kepware, TI, Activas, Blu-shift, and more) end users from the onset, which helps in keeping the research activities relevant and useful for the participants. Having domain researchers as part of a team with industry professionals creates a diverse and dynamic environment for innovation and cutting-edge research and development. A current industry participants list will be augmented as more companies are identified along the way during the implementation phase of this project. Active recruitment will take place during our annual conference that highlights students and faculty accomplishments each year. Invited speakers from industry will get to see student work and to provide valuable practical feedback during these annual events. The need for more workforce in the wireless engineering area is real and urgent. This proposal will help fill that gap by preparing more students in the area of broadband access and sensing to serve the needs of Maine and the nation.

***E. Infrastructure**:* It is critical to note that the existing physical infrastructure at UMaine funded by MTI and local industry (Maine Center for Next Generation Wireless Communications $2.2M including 4 labs) need to be augmented by investing in human resources (new faculty, technicians, research admins and staff). In other words, UMaine is well-positioned to attract highly qualified researchers in the wireless broadband and sensing area and can quickly produce new technologies with commercial value (this has been proven in small scale on shoestring budget with great potential to scale up).

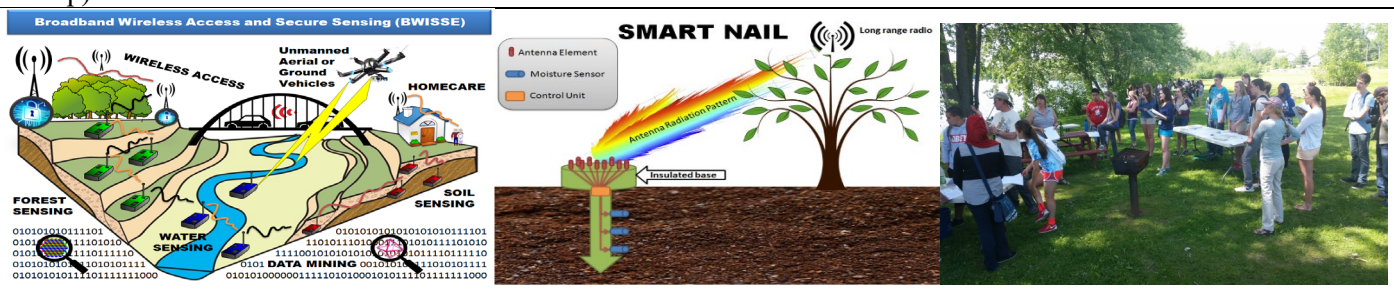


**Figure-1:** From left, Proposed network architecture, Smart nail sensing idea, and outreach example.

[2]wttc.org/-/media/files/reports/benchmark%20reports/the_comparative_economic_impact_of_travel__tourism.pdf