MadNEST --- An Infrastructure to Foster Wireless Innovations at City-Scale

This project proposes to develop, deploy, operate and manage a city-scale next-generation infrastructure for advanced wireless research, called *MadNEST*, through a significant collaboration. The multi-dimensional team deeply incorporates academia-government-industry partnership and includes researchers and technical leaders at the University of Wisconsin-Madison; city and county partners across two cities --- Madison and Monona and the local county --- Dane, local industry partners --- 5NINES (a local ISP); the local transit operator --- Madison Metro Transit; vehicle manufacturers (Innova); and end user communities in the domains of transportation and healthcare, and especially providing innovative low-cost Internet connectivity <u>to</u> some under-served communities in the region. MadNEST will include a coverage area spanning about 60 square miles in and around the cities of Madison and Monona that will combine both dense urban hotspots and sparse rural communities, thereby allowing researchers the opportunity to experiment across such diverse settings. MadNEST uses an innovative production-cum-experimental infrastructure design that leverages the team's prior expertise and successes. Below we describe the key architectural components of MadNEST and its related innovations from an experimental standpoint.

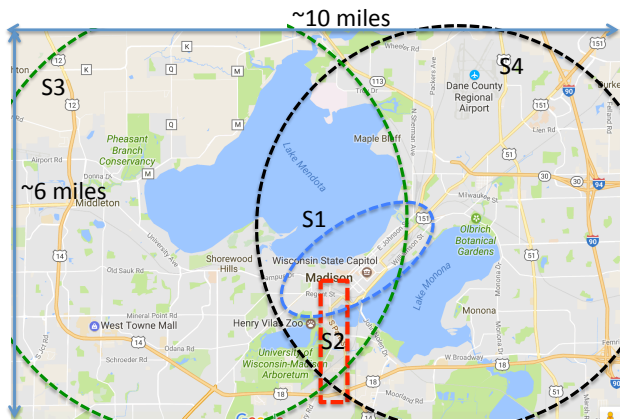## Nature of the infrastructure

Figure 1: Map of Madison and Monona showing the multiple stages of deployment (S1 to S4). Subject to change based on input.

MadNEST will provide an infrastructure for wide-area wireless experimentation at different scales. Some of the most significant application domains are: i) programmable wireless nodes deployed on more than 300 vehicles across the city of Madison, consisting primarily of Madison Metro Transit buses, and also city of Madison emergency vehicles, specialized electric vehicles that are deployed specifically for experimentation, and custom unmanned electric vehicles that will ply across the deployed infrastructure; ii) access to wireless infrastructure to provide low-cost wireless access in parts of rural and under-served populations in Wisconsin; and iii) other applications, such as smart healthcare, as opportunities arise.

1. Preliminary Plan

MadNEST will be developed in an iterative manner through a sequence of four 1-year stages, each increasing in its scale or complexity with a 5th year to complete further integration and refinements.. We describe these stages in turn.

Stage 1 (downtown Madison and controlled infrastructure --- Year 1): This stage would first focus on buildout of core platform components, integration of different components, ranging from radios, base stations, edge and cloud platforms, integration with cloud backends, and web interfaces. Once completed, it will lead to our first wave of deployments of infrastructure which will replace or augment existing locations where the team already has existing infrastructure (from the ongoing WiNEST efforts). This would include at least 4 cellular sites in and around UW-Madison campus and specific other buildings in downtown Madison, WI, replete with the base stations, spectrum analyzers and related backhaul components, all using fiber. In addition, we will also be deploying various micro hotspots in downtown Madison that fall within the coverage area of the initial cellular sites. In addition, we will also be standing up the controlled experimentation facility which will be equipped with the same hardware and software components as the initial downtown deployment, which is located in the far west side of Madison (not shown in the map).

Stage 2 (Park Street smart corridor and vehicles --- Year 2): In the second year of the project we will expand the initial deployment to incorporate vehicle-mounted wireless gateways and edge nodes, with an initial rollout on about 20 Madison Metro Transit buses, upto 10 Innova UEVs, and corresponding roadside infrastructure along the planned smart corridor in Park Street, connecting downtown Madison to highways nearby. This stretch of road also passes through an under-served area in Madison, WI, and will be utilized to provide wireless-based experimental access to this neighborhood.

Stage 3 (Madison west side --- Year 3): In the third year of the project, the goal will be to expand the coverage to the west side of Madison, which is the relatively newer residential areas of the city. We will be deploying cellular infrastructure on various water towers in this area, increasing the number of hotspots to nearly 300, and the number of deployments on city buses to nearly 100.

Stage 4 (City of Monona and Madison east side --- Year 4): At this stage, the deployment will be enhanced to cover the city of Monona, which lies to the south east side of downtown Madison, and to the east side of the city of Madison. We will also be bringing the number of hotspots to 1000, complete macro base station deployments everywhere to cover the entire geographic space.

Additional comments: Stages 3 and 4 are subject to change. Ideally we would like to get a region of Madison that is under-served today and would benefit from new technologies that provide low-cost and high-throughput wireless-based broadband Internet access. This would be an opportunity to show case advanced wireless technologies as well as provide significant benefits to the relevant community.

2. Requirements from partners

Cities of Madison/Monona/Dane County
Identification of about 20 sites on which wireless base stations will be installed. Ideal locations for these base stations would be city water towers, and tall buildings. The city of Madison has provided us with a list of about 10 city towers already, and we need an agreement with the city

to facilitate deployment. The project will cover the costs of installation, and need budget estimate for installation.

Ideal location of such sites would be ones where fiber is readily available or can be brought in.

Also looking assistance in the selection of an under-served area of the city, where we will provide broadband wireless access.

Finally, we will work with a Chicago-based company, called Innova, that might be willing to deploy a set of upto 20 "urban electric vehicles" (UEVs) that will be placed in a) across the city for use by targeted city personnel for short commutes with a rental model similar to Zipcar or b) in a targeted area of the city where perhaps the connectivity to nearest bus stops is not the best, and will be used by the citizens in the area to easily commute back and forth between the bus stops and locations close to home.

In either case, the city is requested help in identifying parking spaces, where such vehicles maybe parked. Also charging stations would also be necessary for these vehicles.

Finally, in specifically identified parts of the city, we would like to deploy unmanned aerial vehicles (UAVs) that will be utilized for improving wireless coverage and spectrum measurements.

Madison Metro

Permission to use part of the cabinet in the vehicles to deploy wireless hardware. Further antennas for these wireless systems will be mounted on the roof of the vehicle. PI Banerjee has done similar installations in the city buses in the past, and this effort will be slightly larger involved in the amount of hardware per vehicle (but not likely to involve extra effort on Madison Metro's part). The wireless hardware will be powered by the vehicle itself. The hardware will be acquired and purchased by the project. The project will provide funding for the deployment and upkeep of this hardware. The plan is to provide this across all or a majority of city buses (~250-300).

Public Safety department (Fire, Police, and Ambulance)

Deployment of similar wireless hardware as in the city buses to provide them with continuous connectivity to the ambulance. Almost the same as above, and it would be ideal if we can pick one or two agencies with about 20-40 vehicles.

Madison Gas and Electric

Permission to install wireless hardware (ruggedized outdoor AP form factor) on utility poles (ideally free of cost). The number of installations will be anywhere between 100-1000 depending on opportunities available. The targeted locations are mostly going to be concentrated in three areas --- a) State Street, b) Park Street corridor connecting downtown and Beltline, and c) a designated part of greater Madison where we can evaluate connectivity to an under-served community from the broadband wireless perspective. Some form of backhaul between these outdoor installations is needed, either fiber or our own wireless.

Finally, access to charging stations, and willingness to develop more charging stations for our 20 UEVs would also be greatly desirable.

Traffic Engineering department (city of Madison)
Collaboration and integration with the smart Park Street corridor plans, whereby it might be possible for establishing a wireless link to the various traffic lights on the corridor that the traffic engineering department might want to remotely control.

Parks department
Identify need for high bandwidth wireless to the parks and lakes in and around Madison. Ideally coverage for some sensing projects, e.g., water sensors on lake Mendota, or other sensing activities in some park. Perhaps start with 1-2 sites.

Library Department??? (optional, but I am told they might be very interested)
Ability to install wireless hardware in the library rooftop to facilitate high-bandwidth connectivity to all libraries.

UW-Madison athletic department
We will like to install some of our mmWave and other experimental wireless hardware in part of the stadium to evaluate wireless performance in a region of very high user density. Experiments will only be conducted on days when there is no scheduled events in the stadium so that it does not interfere with actual operations in a game-day.

American Family drone testing facility
Amercian Family has a region close to Madison which they use for experimentation with drones and other aerial vehicle technologies. We would be interested in talking to them to evaluate whether a subset of our hardware can also be deployed there where controlled experiments can be operated.

Preliminary Sustainability Plan

MadNEST aims to be self-sustainable by the end of the 5-year project period. This will be primarily accomplished through a combination of methods to raise funding. First, we anticipate some funding to be available from local partners and beneficiaries, e.g., the city agencies that use this infrastructure for daily activities. Second, we will implement a subscription model for experimenters, which will include a basic annual fee and a volume-of-use fee. The exact nature of these fees will be determined in consultation with the PPO, the advisory council, and local government in Madison. In the long run, we plan to structure MadNEST as a self-standing non-profit organization which may seek additional operational funding through a combination of other methods, e.g., federal contracts for supporting wireless focused initiatives, industry collaborations, philanthropic gifts that can aid in creation of an endowment, and more. We believe a multi-faceted approach to acquiring funding for such an initiative is critical to its long-term success.