Applications and services leveraging advanced cyberinfrastructure in smart and connected communities
Applications and services leveraging edge and software-defined infrastructures in smart and connected communities
Application Latency

As seen by user

Sensing (Click, camera frame, sensor reading) + Communicating +
Analyzing +
Deciding +
Communicating +
Actuating (or Displaying)
From Washington, DC to Salt Lake City, UT

About 2100 driving miles

At speed of light in a vacuum: 22 msec. round-trip
At speed of light in fiber: 34 msec. round-trip
As fiber is actually routed (on average): 41 msec. round-trip
Including 14 hops: 55 msec. minimum
Due to traffic contention: 57-120 msec.
From Foggy Bottom to GWU

About 0.5 driving miles

At speed of light in a vacuum: 0 msec. round-trip
At speed of light in fiber: 0 msec. round-trip
As fiber is actually routed (on average): 0 msec. round-trip
Including 8 hops by way of SLC: 60 msec. minimum
Due to traffic contention: 60-84 msec.

Tracing route to gw.edu [70.40.219.54] 
over a maximum of 30 hops:

<table>
<thead>
<tr>
<th>Hop</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Host Name</th>
<th>IP Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14 ms</td>
<td>8 ms</td>
<td>4 ms</td>
<td>65.118.40.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5 ms</td>
<td>5 ms</td>
<td>8 ms</td>
<td>dca-edge-21.inet.qwest.net</td>
<td>[65.127.222.157]</td>
</tr>
<tr>
<td>3</td>
<td>62 ms</td>
<td>60 ms</td>
<td>56 ms</td>
<td>slc2-edge-05.inet.qwest.net</td>
<td>[67.14.134.70]</td>
</tr>
<tr>
<td>4</td>
<td>63 ms</td>
<td>65 ms</td>
<td>63 ms</td>
<td>63-232-104-62.dia.static.qwest.net</td>
<td>[63.232.104.62]</td>
</tr>
<tr>
<td>5</td>
<td>81 ms</td>
<td>75 ms</td>
<td>87 ms</td>
<td>69-195-64-129.unifiedlayer.com</td>
<td>[69.195.64.129]</td>
</tr>
<tr>
<td>6</td>
<td>62 ms</td>
<td>81 ms</td>
<td>63 ms</td>
<td>162-144-240-149.unifiedlayer.com</td>
<td>[162.144.240.149]</td>
</tr>
<tr>
<td>7</td>
<td>67 ms</td>
<td>69 ms</td>
<td>61 ms</td>
<td>162-144-240-13.unifiedlayer.com</td>
<td>[162.144.240.13]</td>
</tr>
<tr>
<td>8</td>
<td>71 ms</td>
<td>71 ms</td>
<td>84 ms</td>
<td>70-40-219-54.unifiedlayer.com</td>
<td>[70.40.219.54]</td>
</tr>
</tbody>
</table>

Trace complete.
From U. Utah to Xmission.com (in SLC)

About 5 driving miles

At speed of light in a vacuum: 0.05 msec. round-trip
At speed of light in fiber: 0.08 msec. round-trip
As fiber is actually routed (on average): 0.10 msec. round-trip
Including 8 hops by way of SLIX: <1 msec.
Due to traffic contention: <1 to 2 msec.
Cloud Ping Times (Round-trip)

To popular clouds

<table>
<thead>
<tr>
<th>Service</th>
<th>From SLC</th>
<th>From Foggy Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon EC2:</td>
<td>50-61 msec.</td>
<td>4-38 msec.</td>
</tr>
<tr>
<td>Google Cloud Engine:</td>
<td>1-26 msec.</td>
<td>3-6 msec.</td>
</tr>
<tr>
<td>IBM Softlayer:</td>
<td>41-47 msec.</td>
<td>41-60 msec.</td>
</tr>
<tr>
<td>Nearest Akamai cache:</td>
<td>18-46 msec.</td>
<td>4-6 msec.</td>
</tr>
</tbody>
</table>
100 nsec 1µsec 10µsec 100µsec 1msec 10 msec 100 msec 1 sec 10 sec

Indoor geolocation  High speed trading  Synchrophasors  Vehicle motion control  5G response time  Haptic telesurgery  Human robotic control  Serious gamers  Streaming VR  LOLA  Webcam internal latency  Connected Collaboration  Skype  3D telerehabilitation

Digital  Biological  Annoying  Physical
What would a Metro Internet look like if it were designed to support applications and services for:
- Internet of Things (IoT)?
- Billions of wireless devices?
- Industrial Internet?
- Trustworthy devices?

It would be sliceable & edge-centric with co-optimized gigabit access. = Locavore
What are the categories of Killer Apps for Locavore?

Big
Quick
Special Handling
Big = (often) gigabit or greater

<table>
<thead>
<tr>
<th>Generic</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time HD, 4K, or greater video</td>
<td>Wayne State real-time video fusion</td>
</tr>
<tr>
<td>Real-time manipulation of a large model</td>
<td>City planning with realistic 3D models and surfaces</td>
</tr>
<tr>
<td>Ultra-high resolution images</td>
<td>DICOM medical images being read remotely</td>
</tr>
</tbody>
</table>
## Quick = Low latency

<table>
<thead>
<tr>
<th>Generic</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>In sync with the real world</td>
<td>Augmented reality</td>
</tr>
<tr>
<td>Streaming VR</td>
<td>Feeding low-cost classroom VR headsets</td>
</tr>
<tr>
<td>Cyberphysical Systems</td>
<td>Industrial Internet controllers</td>
</tr>
<tr>
<td>Generic</td>
<td>Example</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>Privacy needed</td>
<td>Putting medical records in a protected slice</td>
</tr>
<tr>
<td>QoS per slice</td>
<td>Public safety video communications (FirstNet)</td>
</tr>
<tr>
<td>Application distributed between edge clouds</td>
<td>Pollution Visualizer</td>
</tr>
</tbody>
</table>
What are the categories of Killer Apps for Locavore?

Big
Quick
Special Handling
Smart Gigabit Community

Share an application ecosystem with all other SGCs
Common scalable execution environment
Each community develops and shares 2 apps per year
15 communities = 30 apps per year
Communities interconnected

Initial cities partly funded by National Science Foundation
Additional cities self-funded or sponsored privately
Smart Locavore Infrastructure

= Digital Town Square

Local GENI racks
Interconnected city-to-city via AL2S
Interconnected to city broadband head-ends

Paradrop ultra-locavore compute + wireless

Available for your experiments and apps
Smart Locavore Community

- Streaming virtual and augmented reality
- Interactive 4K video
- Personal assistants think faster than you do
- Intra-beat cardiac monitoring
- Streaming intelligence to inexpensive robots
- Microgrid millisecond coordination
- City-wide optimized autonomous vehicles
- Big Data analytics
- Hospital-quality in-home health monitor
- Real-time public safety information fusion
- Dynamically optimized emergency response
- Interactive & collaborative 3D model design
- 3D telerehabilitation
- Resilient local services
BIOLOGY

The collaborative gigabit app developed and piloted between USC and Chattanooga has led to the development of Chattanooga as the hub of a hub and spoke model with SGC spokes for using the telemicroscopy app for high school education. Chattanooga is developing high school biology curriculum for telemicroscopy and Flint, MI is planning to do the same after a recent telemicroscopy pilot with USC. Both of the US Ignite SGCs are plan to explore extending this technology to other remote instruments such as electron microscopes and telescopes.

Chattanooga has extended the use of 4k video streaming over their gigabit network to streaming Tennessee Aquarium content to the Tennessee airport and to Burlington, VT through a collaboration. Other SGC’s plan to do the same as part of the SGC initiative.

WHAT IS IT?

The interactive, high-resolution microscopy system enabled researchers at USC to place live biological specimens under a Digital Cinema Microscope and capture ultra-high resolution (4k) movies of the microorganisms, while simultaneously transmitting live, high-definition images from the microscope system to high school students in a STEM class in Chattanooga. Under the video guidance of the USC researchers, STEM students were able to enhance their learning by manipulating the microscope effectively to view microorganisms with very low latency from 1800 miles away.

BENEFITS

- Chattanooga STEM students gain access to researchers, research-grade microscope, 4K microscopic images, and knowledge from 1,800 miles away
- Students able to learn about and manipulate research-grade microscope in real time
- Analysis of Pacific microorganisms integrated into STEM biology curriculum
- Low-latency gigabit networks enable three simultaneous streams: high-resolution images, video conferencing, and microscope manipulation
- Chattanooga GigTank team to make software more user friendly and create biology curriculum
- Chattanooga to build a hub and spoke model for the gigabit networked microscope

National Priority Area: Education
App stage: Deployed
Gigabit: Low latency, interactive streaming audio and 4k video, real time microscope manipulation
Scalability: Applicable across SGC’s, extendible to other remote instruments

References
EAGER: US Ignite: Digital Tele-Microscopy in Support of Teaching Biology (Award Abstract #1451220)
NSF Article: http://nationalsciencefoundation.tumblr.com/post/114678854343/networked-microscope-enables-cross-country
This project is an example of powerful use of gigabit through a collaboration between the University of Vermont and the University of Tennessee Chattanooga that would not have been possible without the community relationships driven by US Ignite. This project was recently funded by NSF.

**WHAT IS IT?**
This project allows for monitoring and mapping underground infrastructure by integrating gigabit network-enabled sensing and mapping, cutting-edge networking, and data analytics. These real-time and automated sensing and mapping techniques can improve maintenance and management operations through better planning, incident response and condition assessment. Combining several innovative concepts mapping using new low energy Ground Penetrating Radar (GPR), monitoring of infrastructure through high bandwidth/low-latency IoT acoustic arrays, and real-time visualization tools using augmented reality overlays.

**BENEFITS**
- Hardware and survey techniques developed by UVM along with analysis algorithms, interfaces and Hadoop systems designed by UTC
- Cost effective GPR at wider scale
- Higher speed than most current underground monitoring
- Wider field of view on scan
- Fast/real-time detection of pipe damage
- Fiber networks & edge computing indispensable
- Collaboration with SGC (Chattanooga) expanding project
- Greater return for infrastructure improvement projects

**National Priority Area: Energy**

**App stage:** Hardware prototypes, software development

**Gigabit:** Streaming data and uncompressed audio, from IoT devices, augmented reality visualization.

**Scalability:** Applies to urban infrastructure in all SGC’s

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**References**
US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Smart Mapping, Monitoring and Managing Underground Urban Infrastructure (NSF Award #1647095)
EAGER: Underground Infrastructure Sensing, Mapping and Modeling for Smart Maintenance, Sustainability and Usage (NSF Award #1640687)
VR is a prominent and emerging commercial technology with streaming VR as an excellent use case for gigabit speed networks. The University of Louisiana at Lafayette has been able to develop a VR prototype app that requires gigabit speed for use in education and workforce development. This project is being supported as a US Ignite Smart Gigabit Community (SGC) app and funded by NSF. US Ignite is also supporting the development of streaming VR apps and integration of VR labs within innovation centers as part of the SGC network.

WHAT IS IT?
This App enables students to meet in VR with live networked teachers or experts in a 3D environment to provide students with instruction, especially those who cannot travel to a real facility for educational benefit.

BENEFITS
• Ignite the transformative potential of high-performance networks and low cost VR devices for collaborative exploration of 3D environments for educational uses and workforce development.
• Leverages the City of Lafayette’s innovative "Fiber-to-the-Home" project that has brought high-speed fiber optic internet access directly to every school and home in the city, including the David Thibodeaux STEM Magnet Academy, the target high-school for the project.
• It is being used for sustainable energy technologies education. Leverages an existing non-collaborative VR tour of a "Virtual Energy Center" that was developed to explain solar thermal power and other alternative energy concepts to high school students. It models the UL Lafayette Pilot Concentrating Solar Power (CSP) Plant in Crowley, Louisiana, a real-world research facility for alternative energy sources.
• Students who cannot afford to travel to facilities can extract similar educational value via VR.

National Priority Area: Education/Energy
App stage: prototype
Gigabit: VR, Real time streaming audio and video
Scalability: Anchor institutions, workforce development, virtual field

References
EAGER: US Ignite: Collaborative Exploration in Networked VR Environments, and Application to Remotely-Guided Classroom (NSF Award Abstract #1451833)
The Next Generation Business Emergency Operations Center (NextGen BEOC) is a public safety platform that supports gigabit apps for enhanced functionality during a disaster. Lafayette is the emerging leader for scalable gigabit public safety apps that can be deployed across communities with planned deployments in SGCs. A beta version of the NextGen BEOC was deployed in 2015 by the City of Cincinnati to coordinate private sector preparations and logistics during the Major League Baseball All-Star Game and LA BEOC during the most recent 2016 flooding in Louisiana.

WHAT IS IT?
The NextGen BEOC is based on the Louisiana Business Emergency Operations Center (LA BEOC) that serves as the communications portal between the Louisiana State Emergency Operations Center and the state’s private sector businesses and non-profits during a disaster. The NextGen BEOC provides cognitive and physical architectures for collaborative decision-making and crisis management based on a multi-agency, public-private partnership model.

BENEFITS
• A platform that supports gigabit apps for superior disaster preparation and response
• Information display, communications, and decision-making systems enhance situational awareness, collaborative planning and mission support across private-sector entities, non-profit organizations, and citizen groups involved in disaster response and recovery
• Examines concepts for disaster management in virtual environments to enable distributed coordination of emergency management functions independent of a physical EOC
• CrisisEye gigabit app
  • Crowd sourced data collection using video streams to the incident commander
  • Network fault tolerance where one of the switches loses connection
  • Dynamic QOS control of video resolution by the incident commander
• Assessing Community Resilience Through Integrating and Modeling Human Geography

National Priority Area: Public Safety

App stage: Deployed

Gigabit: Gigabit apps/modules can be easily added. Increased functionality with gigabit.

Scalability: Applicable across US Ignite Smart Gigabit Communities for disaster and emergency management. Discussions in progress

University of Louisiana at Lafayette Michael Dunaway, wmd1519@louisiana.edu

References
EAGER: US IGNITE: A Virtual Crisis Information Sharing and Situational Awareness Platform for Collaborative Disaster Response (NSF Award Abstract #1451916)
Assessing Community Resilience Through Integrating and Modeling Human Geography (Award Abstract #1637343)
REMOTE DEEP BRAIN STIMULATION

University of Utah, Christopher Butson

STORY

This project was pioneered by a team at the University of Utah in partnership with University of Utah Medical center, utilizing gigabit networks on the Utah Telehealth Network. An initial application has been developed with trials in medical clinics and with connection to the Utah Digital Town Square can begin conducting in home trials and expand to a wider regional population for treatment. They are currently seeking area partners and SGC collaborations to for trials.

WHAT IS IT?

Creates a data collection, analysis and adaptive learning platform for a mobile centric Deep Brain Stimulation (DBS) management application currently used for the treatment of Parkinson's Disease. Utilizes in place DBS devices already implanted in the patient to create a remote management system for in home treatment to replace expensive and distributive clinical facility procedures. Collection of data during the procedure also enables individualized treatments for increased effectiveness and potential expansion of treatment to other disorders such as Alzheimer's.

BENEFITS

- Allow development of individualized treatment plans through adaptive learning modules
- Allows regional expansion of treatment options
- Increases the availability of treatment data to medical professionals.

References

US Ignite: Track 1: Remote Management of Deep Brain Stimulation (DBS) Patients Using Utah Telehealth Network (NSF Award Number #1531003)
3D TELE-REHABILITATION

University of Missouri, Kansas City, Dr. Marjorie Skubic and team

STORY
Serial academic intrapreneur Dr. Marjorie Skubic has launched a series of US Ignite applications which have resulted in both academic publications and commercialization. Her first US Ignite project (NSF award 1237970) on full-time, real-time sensing and alerting at Tiger Place, a senior living facility, led to the creation of the Foresite company which is now commercializing this technology. Her latest project (supported by NSF award 0703692) is a low-latency gigabit project for tele-rehabilitation.

WHAT IS IT?
It’s rare that tele-health can be better than in-person health. But Dr. Skubic has done just that. An interactive physical therapy system with quantitative readout helps patients see the therapist more frequently so they can be assessed more frequently, get their exercises updated if necessary, and make sure they are performing them correctly with real-time feedback from the therapist.

BENEFITS
The rehabilitation specialist is able to see live views of the remote patient with overlaid information computed from the 3D sensors at the patient location which enables accurate comparisons of current motion versus previously achieved motion.

FINANCIAL SUPPORT
EAGER: An In-Home Health Alert System with Remote Care Coordination, NSF Award Number:1237970
HCC: Elder-Centered Recognition Technology for the Assessment of Physical Function
NSF Award Number:0703692
Acquisition of a 3D Motion Analysis System, NSF Award Number:0319853

National Priority Area: Healthcare
App stage: Demonstration
Gigabit: Low-latency patient real-time interaction
Scalability: Depends on insurance reimbursement


Skubic, Marjorie. "Smart health vital signs from the smart home." *Pervasive Computing and Communication Workshops (PerCom Workshops), 2015 IEEE International Conference on*. IEEE, 2015.
FITNET
Virginia Polytechnic Institute and State University, Mark Gardner, Robert Summers

STORY
The FitNet app would not have been developed without participation in consecutive US Ignite sponsored hackathons. This is the first US Ignite App to receive VC funding for commercialization, with hundreds of thousands of users in the Apple and Android app stores. FitNet is awaiting wider consumer gigabit access to release advanced capabilities.

WHAT IS IT?
App provides real-time fitness sessions and access to personal trainers with monitoring and robust metrics to enhance the delivery of workouts and wellness.

BENEFITS
• Achieve fitness goals with peers and personal trainer from anywhere with an online fitness studio featuring high fidelity video and social interaction via real-time biometric data
• Short workouts with over 200 free exercise videos ranging from abs to yoga at all intensity levels to fit user schedules, no matter how busy
• Ability to pick a live coach for text and video coaching for motivation, custom workout plans, personal guidance and accountability
• Works seamlessly with Apple Watch to provide real-time heart rate and cardio zone during exercise. Use the selfie mode to improve form, see progress over time and share with a personal trainer
• Showed the effectiveness of live broadcast fitness via gigabit networking and the impact of varying the video fidelity (Award Abstract #1353831). The study utilized the KinectHealth software application, GENI racks and the OpenFlow networking protocol.

National Priority Area: Healthcare
App stage: Deployed
Gigabit: Real time streaming audio and video, data
Scalability: Anywhere, already deployed in Apple and Android app stores

References
EAGER: FitGENI - The Impact of Video Fidelity on Fitness Efficacy (Award Abstract #1353831)
KANSAS CITY GIGABIT ECOSYSTEM

Kansas City, KS, MO

STORY
US Ignite led efforts over the last few years in Kansas City leveraging KC’s gigabit network and local developers has resulted a gigabit applications development ecosystem. A subset of noteworthy apps that have resulted from US Ignite sponsorship includes:

PlanIT Impact
PlanIT Impact is a resource impact tool for the planning, design and construction industries that link locally available geospatial data with a specific development project’s location to provide visually immersive feedback. With PlanIT Impact, client groups, civic leaders, and citizens can be immersed in a planned design scenario through 3D navigation and interactive information. By better understanding the impacts of development, communities can make smarter decisions about how and where to invest, scenarios can be modeled and edited quickly in realtime, allowing for engagement with stakeholders on a new level.

Gigabots
With a Gigabot, educators and students have the opportunity to explore new ideas and create new types of devices not be possible without gigabit connectivity. Gigabots inherently have the capability to communicate with other Gigabots, whether they are local or remote. This provides students the opportunity to explore ideas in autonomy, swarm behavior, and remote sensing not possible with unconnected devices using a live realtime virtual dashboard.

SightDeck
All participants at different locations can see and collaborate with each other and manipulate any 2D or 3D graphics superimposed on the screen behind them. SightDeck collaborations and presentations address the needs of both local and distant participants while simultaneously creating a video image ideal for streaming and recording. The application has wide areas of implementation including education, telemedicine, architectural-engineering, Government, art, business, military, and more.

National Priority Area: Energy, Education, Telemedicine
App stage: Deployed
Gigabit: Real time streaming audio and 4k video, data, 3D visualizations
Scalability: Applicable across SGC’s

References
EAGER: US Ignite: Digital Tele-Microscopy in Support of Teaching Biology (Award Abstract #1451220)
NSF Article: http://nationalsciencefoundation.tumblr.com/post/114678854348/networked-microscope-enables-cross-country
In partnership with

with

with

with

with