Convergence With 5G Applications and Use Case Monetization

The Path to 5G Monetization

A Technical Paper prepared for SCTE by

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1. Introduction

4G was a great leap forward, allowing people to stream music and video on the go. 5G takes it to a different level and is designed to connect many more types of devices than smartphones – anything really. This opens a plethora of 5G applications and use cases ranging from intelligent transportation, smart cities, automated factories, telemedicine and a new wave of enterprise communications.

As a Canadian leader in 5G innovation, Rogers has been developing 5G use cases in several sectors in partnership with Canadian universities and industry consortiums. The objective is to pursue research discoveries and develop new applications of 5G to address societal and economic challenges.

In this paper, we will present case studies from two different sectors to demonstrate how 5G networks have enabled Rogers to accomplish its strategy and objectives. These use cases focused in the sectors of smart transportation and health care.

Taking signalized intersections technology to a new level, Rogers deployed NoTraffic autonomous traffic management system at seven live signalized intersections and two roundabouts at the University of British Columbia (UBC) campus in Vancouver. Reducing pedestrians' delay in crossing intersections, was one of the priorities of this project. The deployment optimized the flow of both vehicles and pedestrians. After two weeks, the project's KPIs indicated it had delivered CO2 reduction of 2.8 tons, with a pedestrian delay improvement of 92 hours and vehicle delay reduction of 182 hours. Total economic value over two weeks was about $6,500.

In the second application, the research team developed an ultrasound system which can perform a remote ultrasound operation under the guidance of an expert sonographer. The sonographer remotely "tele-operates" an untrained person (the follower) wearing a mixed reality headset by controlling a virtual ultrasound probe projected into the person's scene. The pose, force, video, ultrasound images, and 3-dimensional mesh of the scene are fed back to the expert in real time. 5G teleguidance is more precise and fast than verbal/video guidance, yet more flexible and inexpensive than robotic teleoperation. Remote ultrasound teleoperation has the potential to revolutionize healthcare access for first nations and remote communities, where receiving medical services can be a significant challenge. In these areas, where it can take months to schedule and conduct an ultrasound examination, this innovative technology can bridge the gap by enabling real-time, long-distance tele-ultrasound imaging.

Together, these two use case scenarios show how several technologies, such as IOT, 5G, cloud, and sensing, are converging and capable of significantly enhancing both public safety and quality of life.

2. Why 5G

5G technology holds immense importance for industrial use cases due to its transformative capabilities that revolutionize the way industries operate. With its ultra-low latency, high data rates, and massive device connectivity, 5G enables a range of applications that significantly enhance productivity, efficiency, and safety in industrial settings. One key advantage of 5G for industrial use cases is its ability to support real-time communication and control. This enables industries to implement remote monitoring and control systems, facilitating operations in hazardous or hard-to-reach areas without putting human workers at risk. Additionally, the low latency of 5G ensures minimal delays in transmitting critical data, allowing for quick decision-making and response times.

The 3GPP (3rd Generation Partnership Project) service-based architecture (SBA) is a key architectural framework which differentiates 5G from previous generations of technologies. Figure 1 below shows the reference 5G system architecture. It introduces a modular and flexible approach, where network functions are decoupled and communicate with each other using standardized interfaces. This SBA brings several benefits to the 5G ecosystem, including scalability, interoperability, and efficient service delivery. 5G improves on the 4G services over several dimensions:

- Enhanced Mobile Broadband (eMBB): According to the ITU's requirements, 5G should be able to provide peak data rates of up to 20 gigabits per second (Gbps) for downlink and up to 10 Gbps for uplink.
- Critical Communications (CC) and Ultra Reliable and Low Latency Communications (URLLC): In some contexts, extremely high reliability is required. For instance, for remote control of process automation, a reliability of 99.9999% is expected, with an end-to-end latency of <10 ms.
- Massive Internet of Things (mIoT). Several scenarios require the 5G system to support very high traffic densities of devices. The Massive Internet of Things requirements include the operational aspects that apply to the wide range of IoT devices and services anticipated in the 5G timeframe.
- Flexible network operations. These are a set of specificities offered by the 5G system. It covers aspects such as network slicing, network capability exposure, scalability, and diverse mobility, security, efficient content delivery, and migration and interworking.

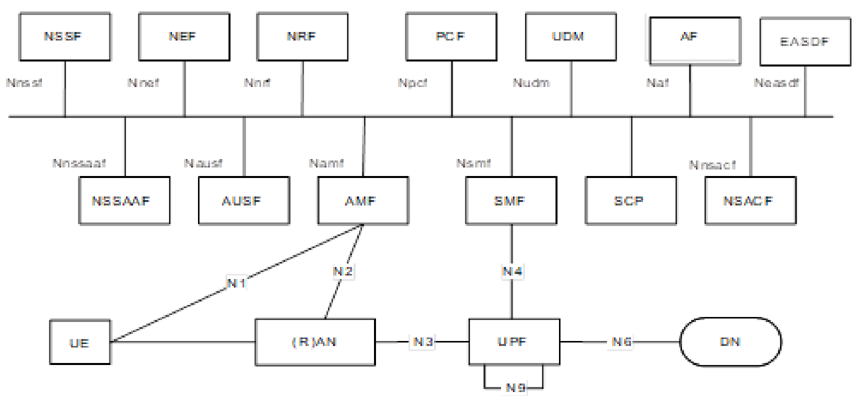


Figure 1- Non-Roaming 5G System Architecture (Source 3GPP : 23501.i10)

One of the important functions in the 5G SBA is the User Plane Function (UPF). The UPF is responsible for handling and processing user data traffic, acting as a data plane anchor in the 5G network. It plays a crucial role in enabling low latency use cases such as gaming, video streaming, smart factory and autonomous driving. UPF is also useful for quality of Service (QoS) Enforcement , Network Slicing, Efficient Data Offloading etc.

With the service based architecture, NFs capabilities are exposed via Representational State Transfer (REST) APIs which are based out of HTTP2.0 protocol. This helps the Application-driven Digital Service Providers which require agility and quicker time-to-market for the products/services rollouts such as advanced automation and robotics in industrial processes.

In conclusion, 5G technology is indispensable for industrial use cases as it enables real-time communication, advanced automation, and massive device connectivity. By leveraging the power of 5G, industries can unlock unprecedented levels of efficiency, safety, and productivity, paving the way for a new era of smart and connected industries.

Rogers plays a significant role in driving and fostering the culture of innovation in the country. Rogers actively collaborates with universities, startups, entrepreneurs, and incubators to support the growth of innovative ideas and businesses. With our partnership with UBC, we are advancing research on several 5G use cases. In the next sections, I am going to present case studies from three different sectors to demonstrate how 5G networks have enabled Rogers to accomplish its strategy and objectives. These use cases are focused in the sectors of smart transportation, public safety and healthcare.

3. Intelligent Transportation POC at Aurora testbed

3.1. Introduction

Rogers and UBC have been working alongside public, private and academic partners with the goal of leveraging 5G to solve problems ranging from traffic congestion and climate change to wildfires and earthquakes. One of the projects is related to intelligent transportation, leveraging UBC's AURORA connected vehicle testbed. The researchers are using the testbed, powered by Rogers 5G, to explore ways to reduce traffic congestion and improve road safety, while also enhancing commercial vehicle operations and efficiencies. As traffic congestion is improved, it also reduces harmful emissions, improving air quality and helping in the fight against climate change.

In a spring 2019 report, Guidehouse Insights forecast that just 7% of North America's signalized intersections would use so-called adaptive traffic-control technology in 2020. On a global level, that number was 2.3%. This means 97% of traffic in the U.S. is not reacting to what's happening on the road.

NoTraffic solved this problem and is enabling the shift from analog traffic-light controls to digital, adaptive systems using artificial intelligence (AI). NoTraffic has developed the first AI-powered traffic signal platform that connects road users to the city grid, solving today's traffic challenges while unlocking smart mobility benefits for the cities, and creating an entirely new way of life.

3.2. NoTraffic System Overview

Figure 2 describes the system overview of the NoTraffic solution. NoTraffic has developed a hardware and software solution to manage traffic in real-time using a network of cloud-linked sensors deployed at intersections, corridors, or grid networks. Intersections may run in a passive data collection mode, detection mode, or optimization mode. The sensors are vendor agnostic and can work with any existing infrastructure. They are compatible with most traffic cabinets, traffic controllers, and power sources. The sensors fuse video and radar for object detection and classification and have a built-in Road-Side Unit (RSU) for Connected Vehicle applications. The sensors communicate to the cabinet equipment wirelessly, so only power is required. The Control Unit is installed in the cabinet near the intersection and interfaces with the traffic signal controller.

All sensors are connected to the cloud using wireless communications and accessed anywhere using the Virtual Management Center (VMC) dashboard. The VMC monitors the proper functioning of the traffic controller and provides real-time alerts if it detects any problems with the traffic controller (E.g., signal in flash, stuck pedestrian calls, communications failure). It also provides alerts from events picked up by the sensors, such as accidents or stuck vehicles.

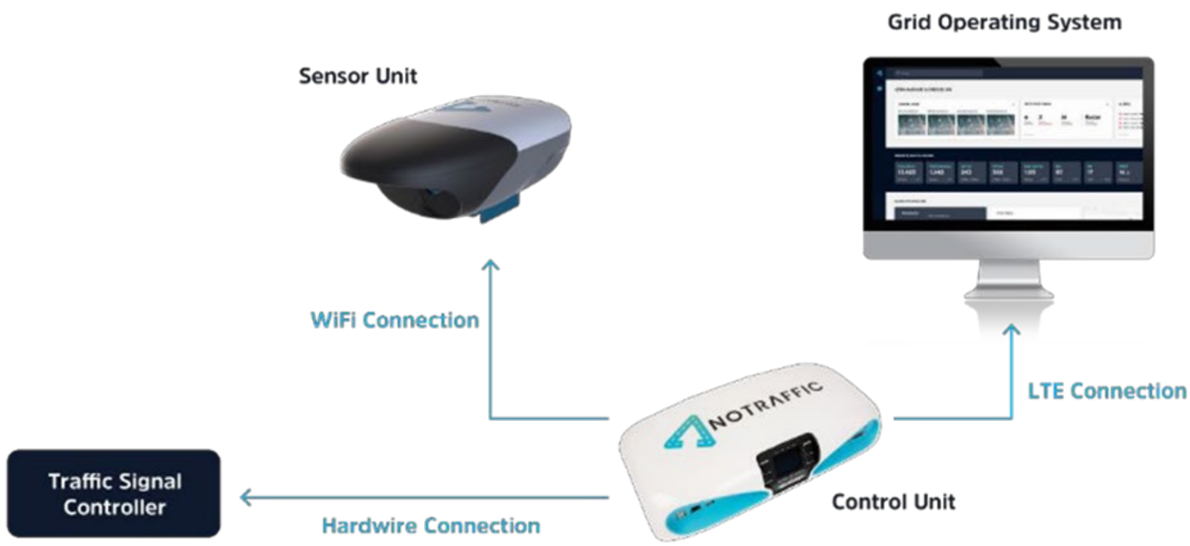


Figure 2- NoTraffic system Overview

3.3. NoTraffic System Deployment

The AURORA testbed is home to the Detection & Traffic Management pilot from NoTraffic. The sensors were installed at seven signalized intersections and two roundabouts across UBC's Vancouver campus. The goal of this project was to digitize the intersections using AI driven detection technology and reduce the traffic congestion and pedestrian delay along the Wesbrook Corridor at UBC campus in Vancouver by using advanced optimization features in the NoTraffic platform. Figure 3 shows the nine locations at UBC Aurora testbed where NoTraffic system was deployed.

NoTraffic system can be run in three different modes of operations:

Passive Mode: In Passive mode, the sensor collects data, but does not actuate the traffic signal. This is a typical application for a roundabout or pedestrian signal. The sensors do still pass traffic demand information to downstream intersections if the corridor/grid is in Optimization mode.

Detection Mode: In Detection mode, the NoTraffic sensors detect vehicles, and provide inputs to the existing traffic signal controller to operate the intersection. The key benefit is nearly 100% accuracy, reduced maintenance costs, and increased reliability of vehicle detections. The intersection still operates using the timing and detector plans programmed in the traffic controller.

Optimization Mode: In Optimization Mode, NoTraffic uses AI to autonomously optimizes traffic signal operations in real-time based on actual demand, and by predicting two minutes into the future. Rather than adhering to a fixed cycle or historical estimates, a predictive system changes, or adapts, based on actual traffic demand in real time. The software uses advanced AI algorithms to track and count vehicles, analyze incoming data, and respond appropriately regardless of intersection geometries or traffic demand changes.

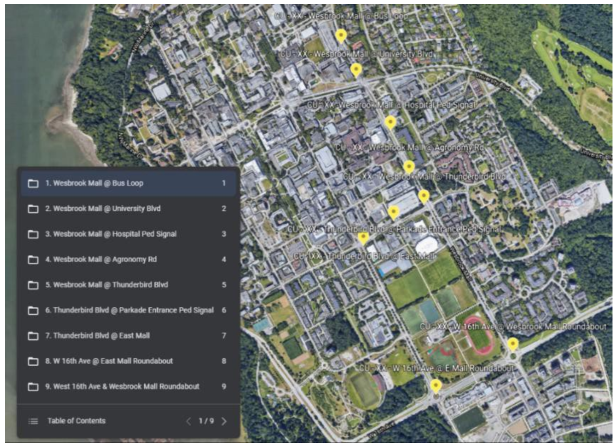


Figure 3- NoTraffic deployment at the 9 locations at UBC

Figure 4 shows a typical installation at one of the locations at Wesbrook and Thunderbird Blvd.

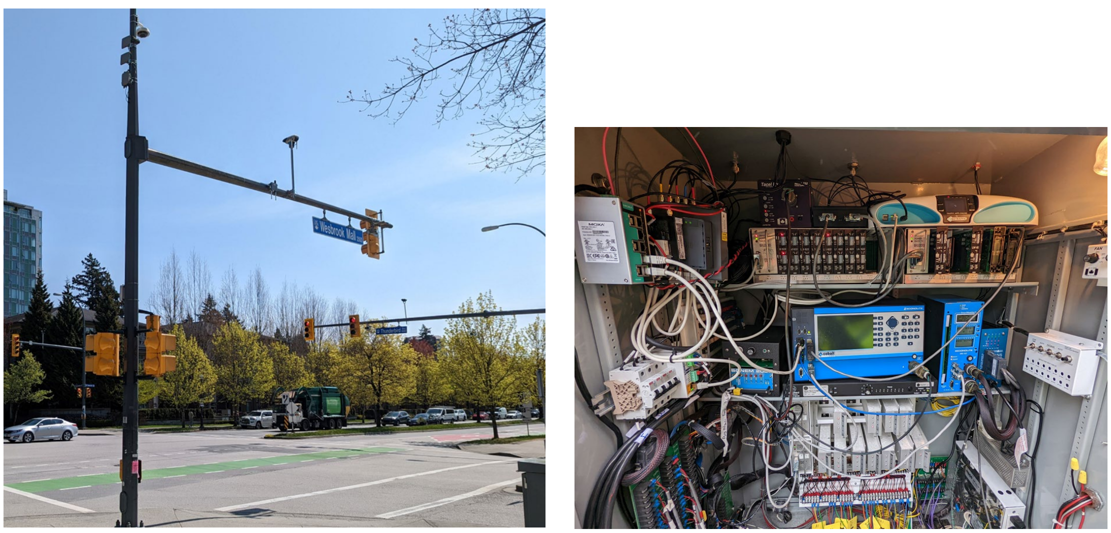


Figure 4- NoTraffic typical installation at Wesbrook-Thunderbird at UBC

3.4. AI based detection

The AI-Based Sensor collects object-based data. These sensors are mounted on each approach to provide a full view of the intersection. This data is collected and sent several times per second, leading to a rich and extensive data set used for optimization and analysis. The data includes:

- Object classification (light vehicle, heavy vehicle, pedestrian, bicycle, and truck)
- Object position (lane, phase, and distance to stop-bar)
- Object trajectory (direction and speed)

The platform also has the capability to place a call into the controller based on object classification. For example, if an agency only wants bicycles detected in a specific detection zone, the object classification of a vehicle will not allow the system to place an output in that detection zone to the traffic signal controller. Figure 5 shows the Pedestrian and Vehicle detection as seen from NoTraffic dashboard.

The AI-powered platform automatically controls traffic light grids, helping to reduce road congestion, coordinate transit and emergency services, and improve safety for drivers, cyclists and pedestrians alike.

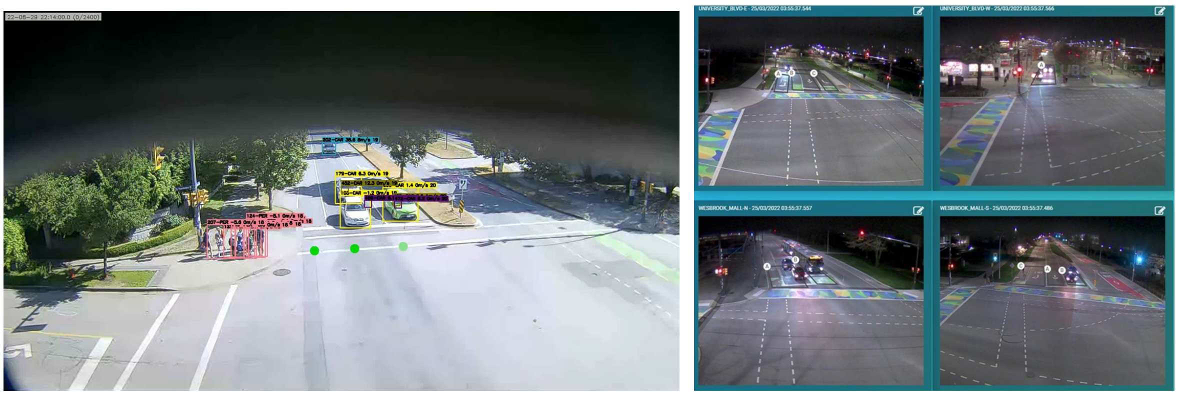
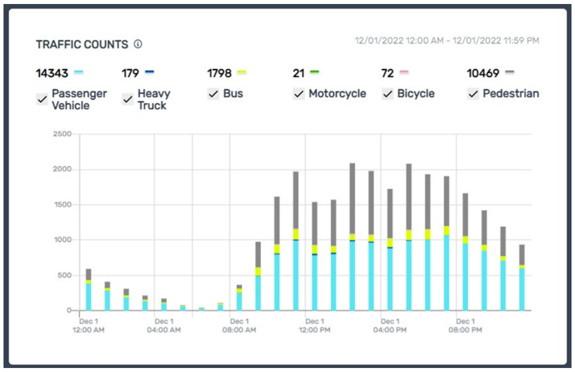


Figure 5- NoTraffic Pedestrian and Vehicle detection

3.5. Results and data collection

Figure 6 shows the counts of different traffic types going through the intersection. The AI-Based Sensor collects object-based data. These sensors are mounted on each approach to provide a full view of the intersection. This type of data supplements connected vehicle technology to improve on the current low penetration of in-vehicle communications devices (DSRC, C-V2X). Each object within the sensor field-of-view is assigned a unique identifier, a position, and a delay. Performance measures can be derived from this rich data set directly from the NoTraffic system, which can reduce costs and the number of different systems to effectively manage traffic for an agency. Figure 7 shows the Vehicle volume data before /after turning of optimization mode. The after scenario has slightly higher volume, which can have an impact on the final results.

Pedestrian delay was the major measure of effectiveness for this project. The research is still new in the industry, but the latest information shows that pedestrians will reduce compliance with walk signals at around 25 to30 seconds. Non-compliance is a surrogate measure for safety. For example, if a pedestrian crosses when they are not supposed to, it may surprise a vehicle and cause a conflict. This reduces the walkability of an area and induces more vehicular demand as pedestrian will not feel safe or adequately served. Furthermore, the higher the pedestrian delay, the higher the difference between “actual” and “perceived” delay, which happens around 25to 30 seconds. The point of this is that each second counts for pedestrians, and their delay is sometimes more important than a vehicle delay.



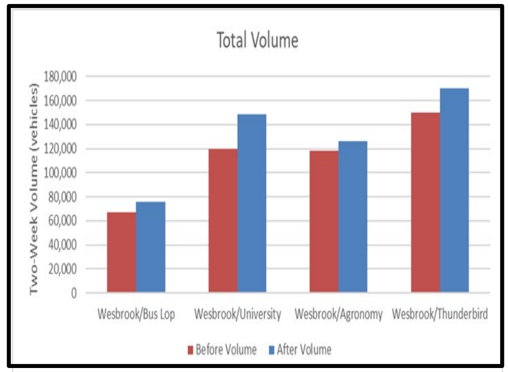


Figure 6- Pedestrian and Vehicle data

Figure 7- Vehicle vol bef/after optimization

For this project, pedestrian delay was reduced by 16% systemwide, or about six seconds per pedestrian. The major mode of travel on campus is via bike or walking. This reduction encourages more trips by foot or non-motorized mode and reducing vehicle-miles-travelled, thereby continuously improving the area and reducing greenhouse gas emissions. Table 1 shows the average improvements for each intersection.

Table 1- Pedestrian delay improvements at 4 Intersections

Intersection	Before, Average Delay (sec/ped)	After, Average Delay (sec/ped)	Improvement (sec/ped)	Improvement Change
Bus Loop	10.56	8.65	1.92	18%
University	20.85	18.96	1.89	9%
Agronomy	18.34	10.43	7.91	43%
Thunderbird	16.64	12.31	4.34	26%

On an annual basis, pedestrians are saved 2,429 hours. In the most critical areas, pedestrian delay was decreased by over 40%.

3.6. Summary from NoTraffic POC

Overall delay was improved across the study area by 7%, with both the non-coordinated and coordinated movements improving. Table 2 shows the vehicle delay improvements across the corridor.

Table 2- Vehicle delay improvements at 4 Intersections

Segmentation	Before, Average Delay (sec/veh)	After, Average Delay (sec/veh)	Improvement	Improvement Change
Main-street (Wesbrook)	16.74	15.49	1.25	7%
Side street	12.42	11.07	1.18	10%
Overall	**28.06**	**26.30**	**1.76**	**6%**

Overall, the NoTraffic system works well in a small context but can have scalable and major improvements on a city-wide basis. Since the system removes legacy requirements, it can have outstanding impacts when deployed across a City, Province, or Region.

The benefits of the system for the scenarios scaled from five intersections over the course of a year are shown in table 3 below along with the benefits if no traffic deployment is scaled and deployed across the full city of Vancouver. The results clearly demonstrate that the deployment of AI-based systems at intersections brings significant economic value through the savings generated from reduced emissions and decreased vehicle delays. By leveraging advanced algorithms and real-time data analysis, these intelligent systems optimize traffic flow, resulting in smoother and more efficient movement of vehicles. As a result, there is a substantial reduction in the time spent idling at intersections, which translates into lower fuel consumption and emissions. The monetization potential arises from collaborations with municipalities and traffic management agencies by digitizing the intersections and generating useful data. The advanced data analysis from the intersections can provide real time traffic and accident insights which can potentially help municipalities to monetize with the insurance companies.5G technology effectively addresses the challenge of dense sensor deployments by offering increased capacity, higher bandwidth, and lower latency. To increase spectral efficiency, 5G networks employ cutting-edge techniques like massive MIMO (Multiple Input Multiple Output) and beamforming. This means that more devices can be connected simultaneously within a given area without experiencing significant degradation in performance. In addition functionalities like network slicing can be customized to meet specific QoS requirements of the ITS industry.

Table 3- City-Wide estimates based upon intersection results

Metric	**2-week results on UBC Campus**	**…Scaled Annualized UBC Campus**	**…if scaled across Vancouver (city)**
Number of Intersections	5	5	727
[1]Total Economic Value ($CAD)	$6,371	$165,654	$84,108,701
CO2 Reduced (Tons)	2.8	74	52,726
Pedestrian Delay Reduction	93.42 (hours)	2,429 (hours)	55,164 (days)
Vehicle Delay Reduction	181.67 (hours)	4,723 (hours)	139,921 (days)

[1] *Benefit numbers are calculated based upon UBC data with inputs from several NoTraffic deployments across North America.*

4. Mixed Reality Human Teleoperation

4.1. What is a Teleoperation

In today's world, mobile connectivity is a lifeline for many communities. It helps some of the most vulnerable people in places where timely medical assistance cannot be obtained. 5G promises to bring high speeds with low latencies which could advance telemedicine applications to a new level.

Telemedicine allows healthcare professionals to assess, diagnose, and treat patients from a distance using technology and other wireless communication devices. With telemedicine, patients don't have to go to their health care professional as frequently because health care specialists can make diagnoses and other specific treatments remotely. One popular way of providing telemedicine is through online video chat.

Current teleguidance methods include verbal guidance and robotic teleoperation, which present tradeoffs between precision and latency versus flexibility and cost. We present a novel concept of human teleoperation which bridges the gap between these two methods. We developed an ultrasound system which can perform a remote ultrasound operation under the guidance of an expert. The Expert (sonographer) could be connected to a wired network (in clinic) or a wireless network (in ambulances) to guide an untrained person (follower) at a remote community connected to a wired or wireless network.

An expert (sonographer) remotely "tele-operates" an untrained person (the follower) wearing a mixed reality headset by controlling a virtual ultrasound probe projected into the person's scene. The follower matches the pose and force of the virtual device with a real probe. The pose, force, video, ultrasound images, and 3-dimensional mesh of the scene are fed back to the expert in real time. In this control framework, the input and the actuation are carried out by people with near robot-like latency and precision. This allows teleguidance that is more precise and fast than verbal/video guidance, yet more flexible and inexpensive than robotic teleoperation.

4.2. Current Challenges

Though some robotic tele-ultrasound (US) system has been used in clinical trials, commercial success has been limited despite the robots' ability to provide precision, low latency, and haptic feedback. This is likely due to time consuming set-up, restricted workspaces, cost and complex maintenance and operation. The cost is notably significant when contrasted to relatively affordable US devices making such systems difficult to deploy in small communities. Despite this, a large body of literature has studied autonomous robotic US-using force-based positioning, depth camera-based planning , and reinforcement learning. However, guaranteed robustly safe human-robot interaction is an issue, particularly for regulatory bodies, and robotic tele-US remains relatively impractical.

On the other hand, there are several commercially available video conferencing-based mobile systems. Butterfly Network, Clarius Mobile Health Corp., and Philips use a point of care US (POCUS) device with live imaging and video conferencing available via a cloud interface on a mobile phone or tablet. Some visual guidance can be given by overlaying arrows or pointers on the US image. Though accessible and inexpensive, these systems are designed rather for quick expert review of a capable sonographer's captured images. The resulting interaction is thus very inefficient leading to low precision and high latency.

The existing options are neither flexible and accessible nor accurate and efficient. However, recent advances in extended reality (XR) research may solve this issue. There are many definitions and classifications pertaining to the approach of augmenting the user's view, including Milgram and

Kishino's "reality-virtuality continuum" , and more recent additions. We refer to our system as mixed reality (MR) in comparison to AR where overlays are applied to videos. In MR visual guides can be located within the real environment itself through the use of optically transparent headsets and waveguides. The ability of MR to project 3D visual information seamlessly into the real world is the key enabling technology in a new concept we call "human teleoperation", introduced in , which leverages MR, haptics, and high-speed communication to bridge the gap in remote guidance techniques.

In this system, a human follower is controlled as if they were a flexible, cognitive robot through an MR interface. In this way, both the input and the actuation are carried out by people, but with tight coupling, leading to latency and precision more similar to a tele-robotic system. This enables remote guidance that is more intuitive, accurate, and efficient than existing audiovisual systems, yet less expensive, more accessible, and more flexible than robotic teleoperation. To accomplish this, the communication system must have a high throughput, low latency, and be adaptable to various networks and signal conditions. The visual control system should be user friendly for the follower and lead to good accuracy and little lag. Similarly, the expert should have a sensation as close as possible to carrying out the procedure in person, called teleoperation transparency, which involves visual, positional, and force feedback.

4.3. Human Teleoperation System Architecture

Figure 8 shows the overview of human teleoperation system. Traditionally in teleoperation systems, there is a local agent, often a robot, which interacts with its environment, and a remote operator who receives feedback from the local agent and provides instructions on what actions to carry out.

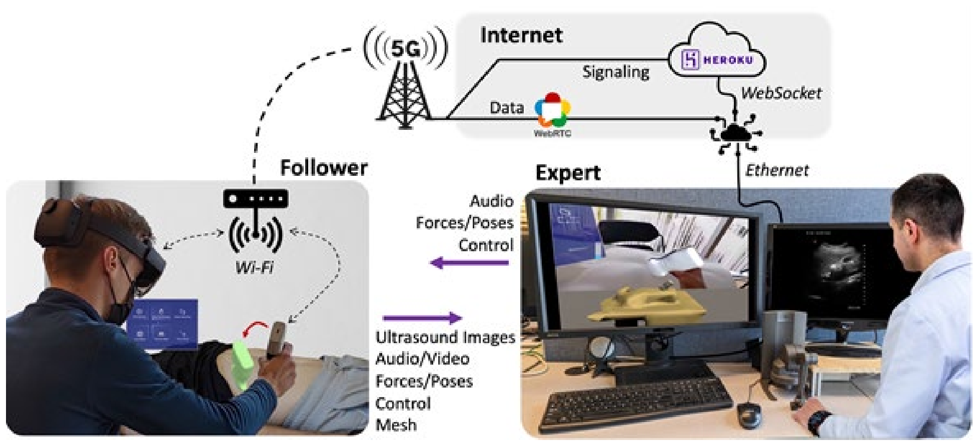


Figure 8- Overview of Human Teleoperation system

In human teleoperation, the local agent is a human, the "follower", while the remote operator is experienced in the task being performed, and is referred to as the "expert". For teleultrasound, the expert is a sonographer or radiologist with ultrasound experience, and the follower is an inexperienced novice, whose interactions with his/her environment constitute moving an US probe on a patient, as instructed by the expert.

The follower wears an MR headset, the Microsoft HoloLens 2, which projects a virtual US probe into their field of view. To perform the desired procedure, they align their real US probe with the virtual one and track it as it moves around on the patient. In this way, the desired position and orientation (pose) of the probe are achieved. The desired force is similarly reached through a visual control system.

The desired pose and force of the probe are set in real time by the expert, who manipulates a haptic device (Touch X, 3D Systems, Rock Hill, SC). This is a small, 6-degree-of-freedom (DOF) serial manipulator that measures the 6-DOF pose of its pen-like handle and applies 3-DOF forces to the handle's tip for haptic feedback. As the expert grasps the end-effector and carries out his/her desired motion, the probe pose is transmitted to the virtual handle guiding the follower. The haptic device applies forces back to the expert. By pushing against them, the expert also inputs his/her desired force.

One of the primary objectives of the system is teleoperation transparency, or making the expert feel as if they are performing the procedure in person by matching the expert and follower positions and forces. To this end, a three or four-channel architecture is required, in which force and velocity are sent from expert to follower and vice versa at a high rate. Hence, the desired forces and poses are sent from expert to follower, along with an audio stream and some control packets. Conversely, the measured force and pose of the follower are returned to the expert, along with an audio stream, a video stream captured by the HoloLens which includes the virtual objects in place (called an MR capture), the live ultrasound images, control packets, and occasional mesh data.

In this way, the expert sees the patient, ultrasound probe, and ultrasound images live, and feels the applied forces. She/he consequently decides how to move and performs the motion on the haptic device, which updates the input signal to the follower through the visual control system, which the follower tracks. At the same time, the expert and follower are in verbal communication. Preliminary experiments with carrying out a remote ultrasound examination by a novice follower when teleoperated by an expert have shown promising results.

4.4. Communication network requirements and performance results

The throughput requirements on the follower side are outlined in Table 4. As the expert is stationary and attached via a wired connection, their throughput is of less concern.

Table 4. Worst-case uplink and downlink data throughput requirements on the follower side

Type	Uplink	Contents	Downlink	Contents
Timing	1.28 Kbps	64 bit long int × 20 Hz	3.84 Kbps	3 64 bit long ints × 20
Force	16 Kbps	3 32 bit floats + 1 64bit timestamp × 100 Hz	16 Kbps	Same as uplink
Pose	28.8 Kbps	7 32 bit floats + 1 64 bit timestamp × 100 Hz	28.8 Kbps	Same as uplink
Video	≈1-2 Mbps	960 × 540 px H.264 encoding, 25 Hz, Variable quality	0	No
Audio	128 Kbps	Typical MP3 bitrate (Part of MPEG-4 stream)	128 Kbps	Same as uplink
US	4.64 Mbps	58 KB JPEG image (worst-case) × 10 Hz	0	No US
Mesh	2.3 Mbps	≈12k mesh triangles × 3 points and 3 indices × 32bit floats	0	No downlink mesh
Total	6.81 Mbps	Mesh sent rarely on demand. Peak throughput 9.11 Mbps	180 Kbps	Sum

The follower side is mobile and could be installed anywhere, including a moving ambulance or a remote location, it is designed to work over mobile networks. A tight coupling between expert and follower is required. The communication system was designed to minimize latency using the WebRTC (Web Real Time Communication) standard. As shown in Figure 9, WebRTC is a peer- to-peer architecture which eliminates server-related delays. It is built on stream control transmission protocol and real time transport protocol, both of which are related to the user datagram protocol (UDP) which prioritizes speed over reliability.

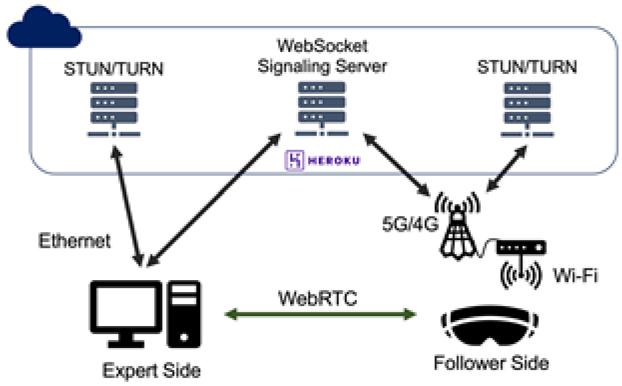


Figure 9- Overview of communication system

WebRTC is built upon Datagram Transport Layer Security (DTLS), so all communication is encrypted and secure, which is important for medical applications.

We carried out tests of the communication performance over WiFi, LTE and 5G networks, in different signal conditions. LTE and 5G tests were carried out from our public network with best effort QoS. Some of the key results are shown in Table 5. We found that the communication performed sufficiently well over 4G or 5G with good signal conditions up to about 5 Mbps continuous throughput, and well beyond this for WiFi or Ethernet. Typical latencies for 5G were 25 to 50 milliseconds which is appropriate for teleoperation with direct force feedback in the case of a relatively soft contact environment like a patient. In future with 5G standalone (SA) network deployments, Ultra-Reliable Low Latency Communication (URLLC) would further enable reduced latencies and a more reliable communication link which is necessary for real-time teleoperation scenarios.

Table 5. Latency(round trip) measurements with different network technologies

Throughput	Ethernet(ms)	WiFi(ms)	LTE(ms)	5G NR(ms)
1.28 Kbps	1.07±0.57	5.80±3.30	38.41±6.63	26.95±7.72
46.08 Kbps	0.94±0.61	5.90±2.77	38.77±7.92	27.67±6.21
2.17 Mbps	0.93±0.59	5.87±1.75	43.49±30.18	39.61±6.14
4.97 Mbps	-	-	52.30±59.30	47.64±22.81

The expert is presented with a live video stream from the follower's perspective, and the ultrasound images of the patient. Based on these, he/she decides how to move. However, the follower coordinate frame is positioned by the HoloLens and varies every time the application is started, even in the same location. Therefore, a registration between the expert and follower spaces is required to ensure that directions in both frames correspond intuitively.

A small sensing element embedded on the probe measures the field from an electromagnetic transmitter to determine the 6-DOF pose. To compare this to the expert's desired pose, the reading must be transformed from the transmitter frame to the HoloLens frame.

Furthermore, the HoloLens 2 continuously captures a 3D spatial mesh of its environment for SLAM purposes. This mesh can be accessed and sent to the expert side to provide 3D visual feedback as well as a haptic interaction.

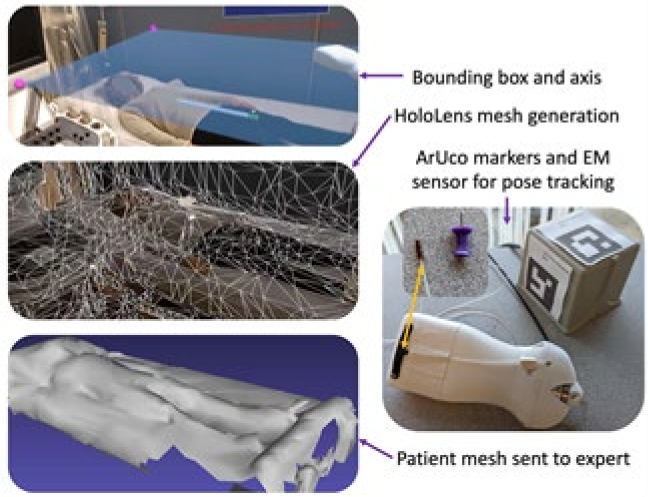


Figure 10- Aspects of expert-follower spatial registration

To extract the mesh of only the patient, not the rest of the room, and to enable the spatial registration, the position and orientation of the patient and electromagnetic transmitter must be determined. The ArUco markers are placed in four corners of the test surface, as shown in Figure 10. The HoloLens automatically determines the poses of the markers and thus finds the patient bounding box, orientation, and the transmitter transform.

4.5. Summary from Human teleoperation

The convergence of augmented reality/virtual reality (AR/VR) and 5G technologies presents a promising possibility for performing ultrasound teleoperation, revolutionizing medical procedures and remote healthcare. This paper has described a novel system for teleoperating a human with precision and latency similar to that of a robot through a mixed reality interface. With this technology, sonographers can perform ultrasound examinations remotely and can guide a novice in real time. This is a crucial service for remote areas where the absence of qualified sonographers could result in simple ultrasound procedures taking several weeks to complete. Monetization avenues arise through offering specialized telehealth packages for clinics and patients, who can benefit from expert consultation without geographical constraints. Additionally, AR/VR and 5G can enhance medical training by enabling trainees to practice ultrasound procedures in a virtual environment, fostering skill development and reducing the need for physical equipment. Ultimately, the integration of AR/VR and 5G technologies in ultrasound teleoperation holds immense potential to improve healthcare accessibility, enhance diagnostic capabilities, and advance medical education.

5. Conclusion

Advancements in 5G, sensor technologies, and augmented reality/virtual reality (AR/VR) are poised to enable transformative use cases across various domains. AI-powered systems can leverage sensor data from cameras, radar, lidar, and other sources to analyze real-time traffic patterns, predict potential collisions, and optimize traffic flow. Traffic management had not changed much for over 50 years. Usually, Traffic lights are timed on a fixed grid, disconnected, not dynamic and cannot react in real-time. With our proof of concept implementation at UBC, we have demonstrated that this can not only safe lives but also brings economic benefits in the savings of fuel costs, emissions and improved productivity and cost savings for businesses and individuals. The monetization potential arises from collaborations with municipalities and traffic management agencies by digitizing the intersections and generating useful data. The advanced data analysis from the intersections can provide real time traffic and accident insights which can potentially help municipalities to monetize with the insurance companies.

5G and AR/VR technologies has the potential to revolutionize multiple industries, offering immersive experiences, real-time connectivity, and enhanced productivity. In healthcare, 5G and AR/VR facilitate remote consultations, surgical assistance, and medical training. Surgeons can use AR/VR to visualize patient data and perform complex procedures with enhanced precision. In this project, we have demonstrated a successful teleoperation which could transform the lives in rural areas. Monetization potential arise through offering specialized telehealth packages for clinics and patients, who can benefit from expert consultation without geographical constraints.

Overall, the high-speed, low-latency and massive device connectivity offered by 5G will unlock new possibilities, drive innovation, and improve efficiency across various sectors, paving the way for a more connected and technologically advanced future.

Abbreviations

ADC	analog-to-digital converter
AI	artificial intelligence
AR	augmented reality
C-V2X	cellular vehicle-to-everything
DOF	degree-of-freedom
DSRC	dedicated short-range communication
DTLS	datagram transport layer security
eMBB	enhanced mobile broadband
FR1	frequency range 1
FR2	frequency range 2
GPIO	general-purpose input output
IOT	internet of things
M2M	machine-to-machine
MEC	multiaccess edge computing
MR	mixed reality
NF	network functions
QoS	quality of service
RAN	radio access network
RSU	road-side unit
SBA	service-based architecture
SLAM	simultaneous localization and mapping
SPI	serial peripheral interface
UDP	user datagram protocol
UPF	user plane function
URLLC	ultra reliable and low latency communications
US	ultrasound
VMC	virtual management center
VR	virtual reality
XR	extended reality

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