BIKES: A Moving Network System for Music and Sound Art

Orlando Kenny
School of Music
Georgia Institute of Technology
Atlanta, USA
okenny3@gatech.edu

Laura Call Gomez
School of Music
Georgia Institute of Technology
Atlanta, USA
lgomez47@gatech.edu

Shirin Sathe
School of Music
Georgia Institute of Technology
Atlanta, USA
ssathe33@gatech.edu

Henrik von Coler
School of Music
Georgia Institute of Technology
Atlanta, USA
hvc@gatech.edu

***Abstract*—BIKES is a network music performance system composed of four electric bicycles, each equipped with an onboard computer and a loudspeaker. The bicycles share control data and metadata over a local-area network, creating sonic interventions in arbitrary locations, either while moving or while stationary, as an installation. BIKES is an instrument in its own right and is intended to be programmed individually for different concepts and compositions using tools such as SuperCollider, Python, and Ansible. This paper discusses the initial prototype, detailing the hardware, software, and network communication architectures used for musical interaction. BIKES has been used in public performances and installations in a variety of urban contexts, displaying the system's novel ways of interacting with its environment. Future developments will focus on enhancing the system's robustness by improving the hardware design and equipping each bike with a router to form a decentralized peer-to-peer network.**

I. Introduction

BIKES is a mobile network music performance system built around a fleet of electric bicycles. Each bike is equipped with an onboard computer, touchscreen interface, and PA speaker system, forming a distributed musical instrument capable of both mobile performances and temporary installations.

Figure 1 illustrates the initial prototype and its mounted hardware configuration. BIKES is driven by both practical concerns and imaginative concepts. On the practical side, electronic music and sound generation have a sustainability problem. Bicycles are a sustainable and accessible way of deploying a multi-channel loudspeaker system to arbitrary locations. From a conceptual perspective, BIKES leverages network music performance principles to act as a flexible and distributed instrument.

The system supports a wide range of network topologies, serving as a medium for creative expression. Performances and installations are centered around the flow of data and the musical interaction between bicycles. BIKES integrates concepts from urban soundscape design, bike hardware design, user interface development, and network music performance. The project is a collaboration between the Georgia Tech School of Music, the Georgia Tech School of Industrial Design, and Edison Electric Bicycles. This paper explores related works, outlines the software and hardware architecture, describes the use of network topologies for creative expression, summarizes the system's first experiences, and addresses shortcomings that will be improved upon with the next iteration.

Fig. 1. A BIKES prototype with audio hardware.

II. Related Work

A. Network Music Performance

Network technology has been an integral component of experimental and collaborative music making. It serves as either a technical backbone for transmitting data or the creative medium itself [1]. In many modern applications, network-based approaches are used for high-fidelity audio streaming, modeled after conventional audio routing systems. Among these, Audio-over-IP (AoIP) protocols have been developed. Dante has become an industry standard for synchronized multi-channel audio over Ethernet [2]. It is mostly used in studios and live performances for its low latency and plug-and-play nature. JackTrip is another system designed for real-time, high-quality audio streaming over the internet and is commonly used in remote collaborative performances [3]. SonoBus offers a similar tool, with an emphasis on flexible network connection topologies, while RAVENNA is used in high-end broadcasting settings and supports precise time synchronization and uncompressed audio over networks [4], [5].

Despite their advantages, all of these systems face latency issues. These issues make real-time musical interaction difficult. Rottondi found that latency in Network Music Performance (NMP) systems is introduced by aspects such as physical distance, routing complexity, packet size, switching infrastructure, soundcard delays, and audio buffering [6]. These constraints make it difficult to create a synchronous system using AoIP principles.

Historically, the transmission of control data as opposed to audio has offered a solution to the synchronous issue. Early examples of network music performance systems employed this principle. The League of Automatic Composers (LAMC) in the late 1970s pioneered this approach by using computers to send musical instructions as opposed to raw audio, laying the foundation for the future development of laptop orchestras [7]. In the 1980s, The Hub developed peer-to-peer control data driven performance systems, using custom protocols to exchange compositional parameters in real time [8]. Later on, Talking Drum was presented as an installation for autonomous sound generation of nodes over a linked network [9].

The latency issues regarding AoIP protocols still hold true to this day. BIKES builds on control-data-driven systems, using modern networking protocols to exchange OSC messages and update parameters rather than transmit audio streams. This allows for a lightweight, robust, and scalable interaction system that is also able to be synchronous and resilient to latency.

B. User Interface Design and Distracted Driving

User interface design is critical for ensuring safety and usability in moving systems. Minimizing distraction is an essential component. Both visual and auditory distractions must be addressed. De Waard found that although both handheld and hands-free mobile devices significantly increase cyclists' reaction times and reduce their auditory perception of their environment, hands-free devices were less distracting [10].

To address this, BIKES uses a handlebar-mounted touchscreen interface and supports autonomous operation to minimize the need for rider input. Another key factor in rider safety is the medium used to deliver sounds. Mwakalonge highlighted the dangers of auditory distractions and concluded that the safest systems were those that allowed users to remain aware of their environment. BIKES employs external loudspeakers for sound delivery. This approach preserves the rider's awareness of their environment while still allowing them to experience the system.

C. Movement in Music and Sound Art

Adding movement to sonic experiences introduces new possibilities for composition, performance and sound design. Various projects have thus explored this avenue in a musical context, creating immersive or site-specific works, either with the listener or the sound sources moving in a defined space. Early examples of the postmodern era, like John Cage's *Musicircus* (1967), or *Persephassa* (1969) by Iannis Xenakis, are based on the movement of musicians and their instruments during a performance to shift the spatial scene.

Using vehicles in this context dramatically shifts the paradigm. Many examples in this domain can be considered interactive sound installations. In his experimental performance *Drive-In Music* (1967), Max Neuhaus broadcasted sounds over multiple FM transmitters in an installation in Buffalo, New York [11]. Any car passing by could receive the signals when driving by, resulting in a shifting scene while moving through the zones created by the different transmitters.

Kaffe Matthews explored different Human-powered vehicles (HPVs) to explore site-specific sound installations for moving audiences. This includes her Sonic Kayaks and the Sonic Bikes [12], [13].

D. Urban Soundscapes

BIKES was created to introduce sonic interventions into urban soundscapes as a form of music and sound art. It is informed by soundscape theory, primarily by the acoustic ecology framework introduced by R. Murray Schafer. Schafer defined modern soundscapes as "low-fidelity environments" in which crucial auditory signals are often masked by overwhelming background noise, resulting in diminished clarity of important auditory information [14]. He goes on to advocate for *acoustic design* as a practice to reclaim sonic environments. BIKES can be seen as a form of acoustic design, intervening in everyday urban soundscapes and introducing signals that are loud and clear.

Schafer also introduces the concepts of *keynotes, signals, and soundmarks* - defined as sounds that structure how individuals experience a place [14]. BIKES contributes soundmarks to urban environments in a transient, mobile, and localized way. Each soundmark creates moments of reorientation and awareness for the audience.

Expanding on Schafer's work, Westerkamp focuses on soundscape composition as a form of artistic engagement with environments. Westerkamp argues that soundscape composition is a dialogical process that fosters awareness of place, time, and environment [15]. Soundscape composition emerges from lived experiences and creates a sense of consciousness for the listener. In this context, BIKES is a system that promotes engagement with urban soundscapes, shaping sonic experiences for the environment's inhabitants.

III. Technology

A. Hardware

1) The Bikes: The initial BIKES prototype is built on a cargo bicycle manufactured by Edison, an Atlanta-based e-bike

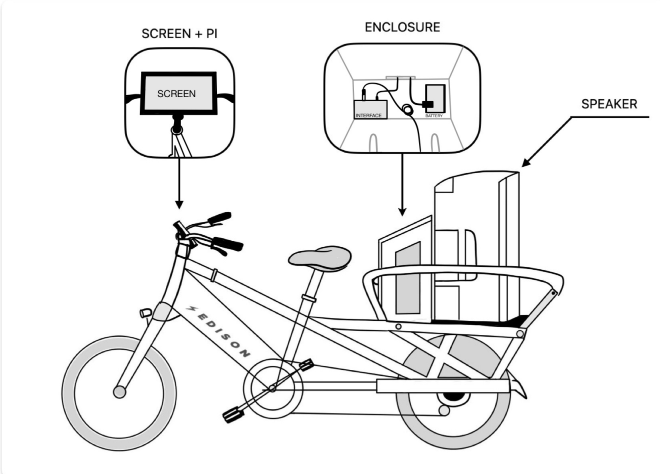

Fig. 2. Prototype setup with mounted hardware.

company[1]. The bike is a class 2 electric bicycle equipped with a 750 W motor and offers pedal-assist and throttle control. It is capable of reaching speeds up to 32 km/h. The bike itself weighs 24 kg and provides the necessary structural robustness needed to support BIKES' hardware configuration. It is powered by a 12V lithium-ion battery and can operate between 40-96 kilometers per charge. The bicycle offers a payload capacity of 181 kg and a towing capacity of 91 kg, allowing for smooth travel when carrying the additional weight imposed by the onboard computer and PA system.

BIKES' industrial design team developed a custom mounting solution for the system. As shown in Figure 2, a wooden platform is mounted onto the back of each bike to support a loudspeaker and an enclosure for the music technology hardware. A 3D-printed screen encasing is fixed to the handlebar and holds a Raspberry Pi and a touchscreen display.

The system uses industrial-grade zip ties to route wiring through the bike. These design decisions resulted in a compact, secure, and reliable setup that works well in motion.

2) Music Technology: Each bicycle is equipped with a dedicated set of technological components that support music generation and network interactions. The main computing unit is a Raspberry PI 5, paired with a 10.1 in touchscreen display mounted on the front handlebars. At the back of each bike, a Mackie THRASH212-GO battery-powered 300 W loudspeaker sits next to a securely mounted wooden enclosure. The wooden enclosure holds a U-PHORIA UMC22 2-in/2-out USB audio interface, a 12V portable battery, and a router (on one of the four bikes). Long USB cables are used to route the system throughout the bike. When powered on, BIKES can operate continuously for two hours without interruption.

B. Software

1) SuperCollider: BIKES uses SuperCollider for audio synthesis and the Graphical User Interface (GUI). SuperCollider uses a sample rate of 44.1 kHz and a buffer rate of 64 samples per block. Each Raspberry Pi runs an independent SuperCollider instance. Communication between bikes is made possible through Open Sound Control (OSC) protocol. Upon receiving a message, the corresponding SuperCollider instance interprets the message's control data and synthesizes audio locally. This event-based communication model removes the need for streaming audio between nodes, reducing bandwidth and enhancing the robustness of the wireless, moving system. It is important to note that although the current implementation of BIKES uses OSC to send control data and synthesize audio locally, there are many other ways that the system could communicate in the future.

BIKES incorporates p2psc and Ableton link to further enhance network communications. Essentially, p2psc is an OSC path registry and message-routing tool that simplifies the configuration of OSC ports [16]. Each bike dynamically registers with the network with a unique identifier and can subscribe to specific OSC paths that are owned by other nodes. This tool allows for rapid routing configuration and can flexibly support different network topologies with minimal overhead. Ableton Link is a peer-to-peer synchronization protocol that aligns beat, tempo, and phase to a shared clock over multiple nodes on a network [17]. BIKES uses Ableton Link to reduce the delay between each bike and ultimately align performance elements to sound cohesive.

2) Ansible (System Management): Rapid configuration and deployment of musical and network concepts is an integral component of BIKES. The system leverages tools from the systems administration domain to ensure a reliable workflow. Ansible is a widely used network automation tool that is used by BIKES to remotely manage each node on the network [18]. Automation in Ansible is achieved by using *playbooks*, which specify a sequence of operations (mostly SSH commands) to be executed on a list of hosts. BIKES uses a set of playbooks to quickly and remotely launch SuperCollider scripts, route different network topologies, and run maintenance tasks. Ansible also provides detailed feedback, indicating whether each playbook ran successfully or failed on each target node. This architecture allows all nodes to be activated simultaneously by a single command-line prompt, resulting in a quick, streamlined, and robust deployment process with an intuitive feedback system.

IV. Network Topologies and Configurations

A. Creativity

BIKES leverages diverse network topologies and routing configurations as a form of expression and creativity. Each network configuration is designed for a specific creative and interactive concept. So far, BIKES has used a few distinct topologies. However, the system architecture supports a wide range of additional configurations beyond what has been presented here.

B. Independent Nodes

In its most basic form, each BIKES node operates independently by executing a local instance of a SuperCollider

[1]https://edisonbicycles.com/

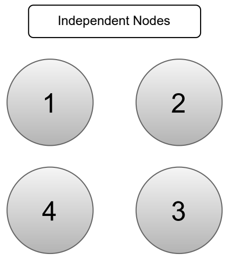

Fig. 3. Independent Network Topology.

script. This mode is referred to as the *Independent Nodes* configuration (shown in figure 3), and does not offer network communication between devices. The SuperCollider script for this setup includes an interactive control interface comprised of a two-dimensional (2D) slider (XY pad) and multiple faders. These controls allow riders to individually contribute to the sonic landscape by manipulating parameters such as pitch and amplitude in real time.

C. Hierarchical

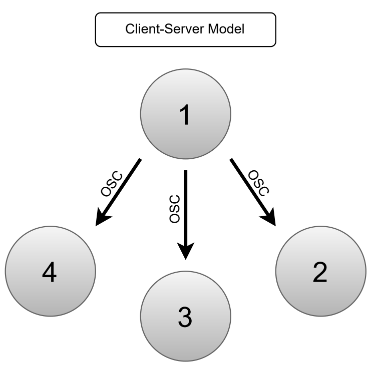

Fig. 4. Hierarchical Network Topology.

In the *Hierarchical* network configuration (shown in figure 4), a single bike functions as the central control node, directing the behavior of all other nodes on the system. The leader node transmits OSC messages downstream to follower nodes, which receive, parse, and generate local sound accordingly. The leader node's SuperCollider script functions as a centralized control node and triggers sounds across all follower nodes. Despite this, each follower node retains the ability to produce sound independently but is subordinate to sonic interventions by the leader node.

D. Forwarding

In the *Forwarding* network configuration (shown in figure 5), each node employs a two-dimensional (2D) XY slider

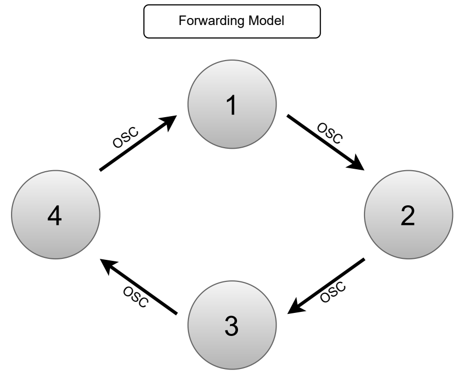

Fig. 5. Message Forwarding Network Topology.

interface and faders to control both local audio synthesis and communication between nodes via OSC. The Y-axis corresponds to the frequency of the generated tone, while the X-axis defines the duration of the tone. When a rider triggers a note locally, the associated control parameters are sent over the network to a designated peer. The receiving node then reproduces the sound locally using the transmitted control parameters. Subsequently, the message is forwarded to the next node and so on, forming a ring topology.

E. Synchronized Clocks

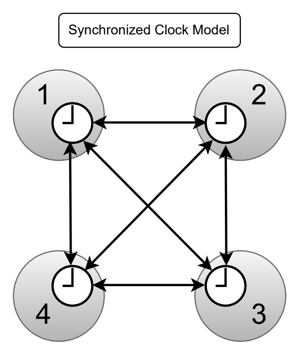

Fig. 6. Synchronized Clock Network Topology.

1) Network Principle: In the *Synchronized Clock* model (shown in figure 6), Ableton Link is used to coordinate tempo, beat, and phase across all nodes on the BIKES network. Link operates with a decentralized peer-to-peer architecture in which each node broadcasts multicast messages to peer nodes. The messages include a unique peer identifier and a snapshot of the node's current musical timeline [17]. Once updates are received from peers, Link employs a consensus mechanism to determine a global timeline reference. Each node adjusts its local timeline to align with the global timeline, resulting in a synchronized system. A key feature of this model is its resilience. Nodes can join or leave the network at anytime without interrupting the synchronization of other participants.

2) Use in BIKES: Within BIKES, the synchronized clock model is used to initiate collaborative musical experiences in which each bike contributes a distinct layer to a larger, tempo-based composition. Ableton Link's built-in peer discovery system and decentralized synchronization process removes the need for manual set up and concern over a node's individual connectivity. This architecture ensures that each node remains time-aligned without needing a leader node, and ultimately produces no latency for listeners during performances.

V. First Experiences

Fig. 7. BIKES field test at the Inman Park Parade.

A. Ride (in motion)

The first field test of BIKES was conducted during the Inman Park Parade (shown in figure 7), a public event held annually in one of Atlanta's historic neighborhoods. Four fully-equipped bikes were deployed to evaluate the system's functionality in a real-world environment.

The parade lasted for over two hours as the BIKES system displayed a distributed musical performance in which each bike played an individual layer of a larger student-made techno composition. Each bike was able to contribute new sounds from riders through the GUI. Throughout the parade, the relative positioning of the bikes changed, causing spatial variations of the soundscape. Minor network dropouts occurred throughout the parade; however, the performance proved to be stable and reliable, proving the feasibility of BIKES.

B. GUI Usage (in motion)

BIKES displayed the *Synchronized Clock* model and the *Independent Nodes* model (discussed in section IV) at the parade. The GUI (shown in figure 8) enabled riders to interact with the system both locally and over the network, creating a collaborative music experience. The GUI supported real-time control of synthesized sound generation and audio processing effects, demonstrating the system's flexibility for expression while in motion. During the field test, riders reported that the GUI felt intuitive and responsive. Riders were easily able to

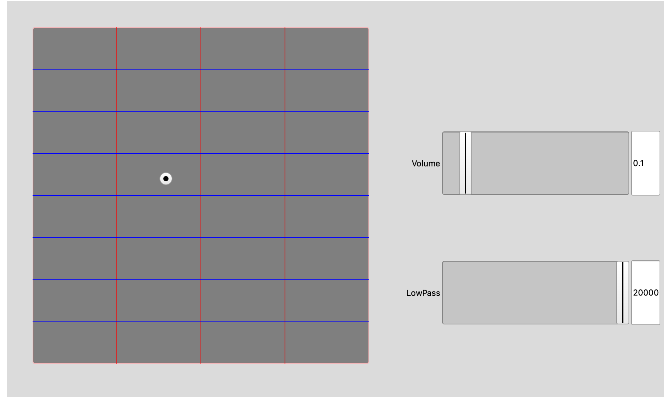

Fig. 8. First GUI iteration.

contribute to the soundscape while fixing their attention on the road. However, riders did report issues with the sun's glare reflecting off of the screen.

C. Installation (Launchpad)

Fig. 9. Buzz (Georgia Tech's mascot) using BIKES at Launchpad.

In another field test of BIKES, the system was displayed at Launchpad (The Georgia Tech Undergraduate Research Symposium), where hundreds of students came together to display their research experiments. A single bike was brought to the venue, where it served as a sitting installation (shown in figure 9). The bike displayed the *Independent Nodes* model, in which each bike generates independent sounds, without intervention from neighboring bikes. The test lasted for over two hours as audience members approached the bike and interacted with it.

D. Discussion

1) Reliability: When evaluating the impact of BIKES on urban soundscapes, it was important to select settings that tested both the technical and creative aspects of the system. The parade display proved to be a suitable testing avenue for the system's ability to contribute sound to an urban soundscape, interact in interesting ways, and be a reliable mode of transportation. Despite the uneven pavement along the parade route, BIKES' hardware remained intact and responsive, with no cable disconnections, power loss, or overheating issues. The installation display tested the system's ability to function as a temporary installation.

Both field tests were successful, as BIKES sustained sound playback for over two hours and retained significant battery life, indicating potential for extended use and highlighting the reliability and robustness of the system.

2) Shortcomings: One of the primary challenges faced during field testing was network dropouts. The dropouts were due to network instability during real-time interaction between bikes. As discussed in section IV, BIKES is a network music performance (NMP) system that sends OSC messages using a client-server model. OSC messages follow the UDP protocol, which does not ensure that messages reach their intended client, instead focusing on sending messages with low latency.

This approach was taken to reduce the overall delay of the system, but proved to introduce network dropouts. In addition to network-related challenges, the system also faced problems with the physical demands introduced by simultaneously riding and interacting with the bikes. The placement of the loudspeaker and enclosure on the rear of the bike altered the center of mass, reducing maneuverability. As a result, riders often spent time maintaining physical control of the system instead of interacting with the GUI.

VI. Conclusion

The initial implementation of BIKES successfully demonstrated the feasibility of the moving system in real-world environments. It demonstrated the system's ability to support musical interactivity across many participants and established a foundation for future development.

A. Hardware Enhancements

Future hardware improvements will focus on the robustness of the system and safety concerns. BIKES will transition to a decentralized network architecture by equipping each bike with an onboard wireless router. This configuration will create a peer-to-peer network architecture that will be more resilient to network dropouts and single-point failures. To address the weight distribution issues on BIKES, new enclosure designs will be developed. They will aim to lower the center of gravity, optimize speaker placement, and improve overall rider stability.

B. Interaction and System Monitoring

Future versions of BIKES will add a new dimension of expression by incorporating motion-based interactions to the system. The system will collect and process the existing accelerometer data from each bike. This feature will enable new forms of dynamic control over the system. The system will also integrate a network status indicator, which will signal when individual nodes are connected or disconnected from the network. This feature will make it easier to pinpoint network related issues on each individual bike. Additionally, future iterations of BIKES may use Audio-over-IP protocols for audio streaming as opposed to metadata-based approaches.

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References

[1] J. Rohrhuber, "Network music." *The Cambridge companion to electronic music*, vol. 8, pp. 140–155, 2012.

[2] Audinate Pty Ltd, "What is dante?" https://www.getdante.com/meet-dante/what-is-dante/, 2025, accessed: 2025-07-01.

[3] J.-P. Cáceres and C. Chafe, "Jacktrip: Under the hood of an engine for network audio," *Journal of New Music Research*, vol. 39, no. 3, pp. 183–187, 2010.

[4] SonoBus, "Sonobus – real-time network audio streaming," https://sonobus.net, 2025, accessed: 2025-07-01.

[5] RAVENNA Network / ALC NetworX, "What is ravenna?" https://www.ravenna-network.com/what-is-ravenna/, 2025, accessed: 2025-07-01.

[6] C. Rottondi, C. Chafe, C. Allocchio, and A. Sarti, "An overview on networked music performance technologies," *IEEE Access*, vol. 4, pp. 8823–8843, 2016.

[7] T. Perkis, J. Bischoff, J. Horton, R. Gold, P. DeMarinis, and D. Behrman, *The League of Automatic Music Composers, 1978-1983*. New World Records, 2007.

[8] V2_Lab for the Unstable Media, "The Hub," https://v2.nl/organizations/the-hub, 2025, accessed: 2025-06-18.

[9] C. Brown, "Talking drum: A local area network music installation," *Leonardo Music Journal*, vol. 9, pp. 23–28, 1999.

[10] D. de Waard, K. Edlinger, and K. Brookhuis, "Effects of listening to music, and of using a handheld and handsfree telephone on cycling behaviour," *Transportation research part F: traffic psychology and behaviour*, vol. 14, no. 6, pp. 626–637, 2011.

[11] L. Kotz, "Max neuhaus: Sound into space," *Max Neuhaus: Times Square, Time Piece Beacon*, pp. 92–111, 2009.

[12] A. G. Griffiths, K. M. Kemp, K. Matthews, J. K. Garrett, and D. J. Griffiths, "Sonic kayaks: Environmental monitoring and experimental music by citizens," *PLoS Biology*, vol. 15, no. 11, p. e2004044, 2017.

[13] K. Matthews, "Sonic bike," https://sonicbikes.net/sonic-bike/, 2014, accessed: 2025-05-23.

[14] R. M. Schafer, *The soundscape: Our sonic environment and the tuning of the world*. Simon and Schuster, 1993.

[15] H. Westerkamp, "Linking soundscape composition and acoustic ecology," *Organised Sound*, vol. 7, no. 1, pp. 51–56, 2002.

[16] bontric, "p2psc," https://github.com/bontric/p2psc, 2024, [Online; accessed 2025-06-09].

[17] F. Goltz, "Ableton link–a technology to synchronize music software," in *Proceedings of the Linux Audio Conference*, 2018, pp. 39–42.

[18] L. Hochstein and R. Moser, *Ansible: Up and Running: Automating configuration management and deployment the easy way*. " O'Reilly Media, Inc.", 2017.