Understanding Quantum-Enhanced Network Analysis for Collective Intelligence

This White Paper began researching at the Network Theory Applied Research Institute (NTARI)

Executive Summary

NTARI is advancing two cutting-edge, quantum-powered platforms as its top-priority minimum viable products (MVPs) known conjointly as **Q-Zoo** to support collective intelligence, digital citizen science, and cooperative internet infrastructure. This white paper presents these MVPs, their technical foundations, and their implementation plans targeted at funders, researchers, policy makers, and NTARI stakeholders:

- **Quantum Community Detection & Social Network Analysis Platform:** A tool leveraging quantum computing (quantum annealing and hybrid algorithms) to detect communities in large networks and analyze social network structure. By harnessing quantum optimization, this platform aims to reveal clusters of tightly connected nodes (e.g., groups of users or ideas) faster or more effectively than classical methods, enabling new insights for researchers and citizen scientists. It directly aligns with NTARI's mission to bolster collective intelligence by mapping knowledge networks and online communities.
- **Quantum Network Flow Optimizer for Cooperative Internet Systems:** A quantum-assisted optimizer for routing and flow problems in community-owned communication networks and civic infrastructures. It uses quantum algorithms (quantum annealing or Quantum Approximate Optimization Algorithm, QAOA) to find efficient paths for data or traffic, reducing congestion and resource use. This optimizer will help cooperative internet initiatives, such as local mesh networks or smart city projects, achieve higher performance with limited resources, exemplifying NTARI's commitment to resilient, community-centric internet systems.

Each MVP offers **unique advantages** over classical tools by tackling NP-hard network problems with quantum methods that explore many possibilities in parallel. The Community Detection platform builds on known quantum modularity optimization techniques, potentially identifying network communities with higher accuracy or interactivity on medium-sized graphs than traditional algorithms. The Network Flow Optimizer addresses complex routing scenarios (e.g. traffic routing, mesh network bandwidth allocation) where classical solvers struggle, as demonstrated by early quantum pilots that achieved notable performance gains (e.g. 15% reduction in mobile network congestion, Read More and 30% fewer vehicles needed in a taxi service simulation). Both projects will be developed as open, collaborative tools integrated with NTARI's existing platforms, showcasing quantum computing's social impact potential.

Implementation Roadmaps: We outline phased development plans for each MVP, starting with small-scale prototypes using available quantum cloud hardware, then pilot deployments in partnership with communities or institutions, and culminating in fully featured platforms. Clear milestones are defined to track progress (e.g., prototype completion, integration with NTARI's Node.Nexus repository, field testing on a community network). We also present estimated budgets for each phase and identify potential funding sources, including research grants (e.g., NSF programs in quantum computing and network science), innovation grants for digital infrastructure, and strategic partnerships with industry or public-sector initiatives.

In summary, **NTARI's quantum MVPs will pioneer the use of quantum computing in network analysis for social good**, bridging advanced technology with grassroots needs. This white paper provides a comprehensive technical and strategic overview to inform grant makers, academic collaborators, and policy champions of the value and feasibility of these initiatives.

Introduction and Background

In an era of rapidly expanding networks and data, NTARI's mission is to **support collective intelligence, digital citizen science, and cooperative internet infrastructures**. Achieving this mission requires innovative tools that help communities understand complex networks (of people, information, or technology) and improve the performance of shared infrastructure. Classical approaches to network analysis – from social network analytics to traffic engineering – are powerful, but often face scaling limits or suboptimal outcomes when tackling the most complex, combinatorial problems (like detecting subtle community structures or optimizing flows with many constraints). Quantum computing promises a new paradigm for addressing such challenges by exploiting quantum parallelism and optimization capabilities to potentially solve certain hard problems more efficiently than classical algorithms.

Why Quantum, Why Now? Quantum computing has progressed from theory to practical experimentation, with quantum annealers and gate-model devices now accessible via cloud services. Early applications in network theory are emerging: researchers have begun using quantum annealing to perform graph partitioning for community detection arxiv.org, and hybrid quantum-classical algorithms have been applied to routing problems in communications networks [Read More]. These successes suggest that even in the Noisy Intermediate-Scale Quantum (NISQ) era, quantum methods can complement classical tools on specific problems. NTARI recognizes an opportunity to become a leader in **quantum network science for social impact** by developing tools that apply quantum optimization to real-world network problems faced by communities and nonprofits. This aligns with NTARI's nonprofit vision – rather than wait for tech giants to dictate the use of quantum networks, NTARI will prototype accessible solutions and ensure they are guided by public benefit and open science.

This document details two priority MVPs where NTARI will focus its initial quantum efforts: (1) a **Quantum Community Detection & Social Network Analysis Platform**, and (2) a **Quantum Network Flow Optimizer for Cooperative Internet Systems**. For each, we provide a deep dive into the technical approach grounded in network theory and quantum computing principles, compare it with the state-of-the-art classical or hybrid solutions, and highlight its unique advantages. We then describe how the project supports NTARI's broader mission and outline a practical implementation roadmap with milestones, budget estimates, and potential funding sources. Figures and tables are included to illustrate key concepts and plans.

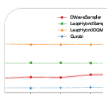
By investing in these MVPs, NTARI and its partners will not only tackle immediate network challenges in areas like online community health and local internet access but also lay the groundwork for future quantum-enhanced tools in collective intelligence. The following sections discuss each MVP in detail.

MVP 1: Quantum Community Detection & Social Network Analysis Platform

Technical Overview

Community detection is a fundamental task in network theory: it involves identifying groups of nodes in a graph that are more densely connected to each other than to the rest of the network. These groups (or "communities") can represent tightly-knit social circles in a social network, thematic clusters in a knowledge network, or functionally related components in a technological network. Formally, a common approach is to maximize a metric called **modularity**, which measures how well a division of the network into communities captures more internal connections than would be expected by chance. Finding the optimal community structure is NP-hard, meaning it becomes computationally intractable for very large graphs using brute force. Classical algorithms (such as the Louvain greedy modularity maximization, spectral clustering, or label propagation) offer fast heuristics that work well in practice, but they may get trapped in local optima and their results can vary depending on initial conditions or approximations.


Community Detection in Electrical Grids Using Quantum Annealing


Quantum Computing, Graph partitioning, Modularity, Virtual ...

Quantum Approach: The Quantum Community Detection tool uses quantum computing to solve the community partitioning problem by formulating it as an optimization task. One method is to encode the modularity optimization into a **Quadratic Unconstrained Binary Optimization (QUBO)** problem. In a QUBO representation, a binary variable is assigned for each possible community assignment of a node, and an objective function (closely related to network modularity) is constructed such that its minimum (or maximum) corresponds to an optimal community division. This QUBO can then be solved by a quantum annealer (such as D-Wave's system), which physically implements an Ising model whose ground state encodes the best community partition found. Alternatively, gate-based quantum computers can tackle the problem using variational algorithms like the Quantum Approximate Optimization Algorithm (QAOA), which iteratively improves a parameterized quantum state to approach the optimal graph partition. Both approaches leverage quantum mechanics to explore many possible partitions simultaneously and potentially escape local optima that confound classical greedy algorithms.

Recent research validates the viability of quantum community detection. For example, a quantum annealing approach was applied to partition an electrical power grid network into communities by maximizing modularity. In comparative tests on small graph benchmarks (e.g., the IEEE 14-bus power grid with up to 5 communities), purely quantum and hybrid quantum-classical solvers achieved modularity values equal to or slightly higher than the best classical methods (Louvain and Gurobi's exact solver). In one case, the D-Wave quantum annealer found a partition with ~1% higher modularity than Louvain's solution, demonstrating that quantum solvers can at least match classical quality and sometimes offer improvement on these problems. While these quantum approaches currently handle only medium-sized networks (tens to low-hundreds of nodes) due to hardware limits, they prove the concept that community detection can be mapped to quantum hardware and solved with high solution quality.

The Social Network Analysis (SNA) Platform aspect of this MVP indicates that, beyond just the core community detection algorithm, NTARI's tool will incorporate workflows to **ingest network data, run analyses, and visualize results**. A user (researcher or citizen scientist) will be able to upload or select a network dataset – for instance, a social network of forum interactions or a citation network of research papers – and request the platform to find communities. The backend will translate the network into the appropriate mathematical form for the quantum solver (e.g., constructing the modularity QUBO matrix or equivalent Ising model). It may employ a hybrid approach: using a classical pre-processing step to estimate the number of communities or to get an initial guess, then refining it with quantum optimization. The result (community assignments for each node) is returned, and the platform provides an interactive visualization of the network with nodes color-coded by community. The figure below illustrates a simple example of community detection on a toy network, where two clear clusters are identified (colored in blue and green):

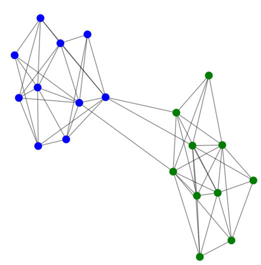


Figure 1

Figure 1: Example of community detection in a network. Nodes that are more densely connected to each other than to the rest of the network are grouped into communities (blue and green clusters). A quantum community detection algorithm aims to find such groupings by optimizing a global objective (modularity), potentially yielding more accurate or diverse community structures than greedy classical methods.

In addition to community identification, the platform can compute other network metrics (centrality measures, cluster densities, cross-community linkage) to enrich the analysis. These classical SNA features complement the quantum core, ensuring users have a one-stop environment for exploring network structure. Over time, this platform could be extended with more quantum-enabled features (for example, quantum influence maximization or link prediction modules) to broaden its analytical power, but the MVP's primary novelty lies in the community detection capability.

Comparison to Classical and Hybrid Tools

Classical Community Detection: The state-of-practice for community detection in large networks relies on algorithms like the **Louvain algorithm**, which is a greedy optimization that merges nodes into communities iteratively to increase modularity. Louvain and its variants are extremely fast and can handle networks with millions of nodes, but they are approximate. Other methods include Girvan–Newman (which iteratively removes edges to split communities) and spectral clustering (which uses eigenvectors of graph matrices to partition nodes), as well as various statistical inference approaches (stochastic block models). These classical techniques are well-supported by open-source tools (NetworkX, Graph-tool, igraph, etc.) and have been the backbone of network science for years. However, they sometimes yield different results on the same data and may miss the global optimum community structure, especially on networks with subtle or overlapping communities. They also typically run in multiple stages or rely on heuristic choices (like initial seeds or the number of communities to find).

Quantum vs Classical: NTARI's quantum platform is not meant to supplant classical methods on all fronts, but to provide a novel alternative that can be particularly valuable in certain scenarios: for example, when the network size is within the manageable range of quantum hardware but the community structure problem is difficult (where classical heuristics might falter). Currently, classical algorithms have the edge in scalability – today's quantum hardware can only handle on the order of up to a few thousand binary variables in a QUBO (which might correspond to a graph of a few hundred nodes partitioned into a few communities, depending on formulation). Indeed, a known limitation is that **quantum annealers have limited qubit counts and connectivity**, which means large real-world social networks must be reduced or coarse-grained to fit on the quantum machine. This MVP will therefore initially target small to medium networks (e.g., a network of a few hundred individuals or articles), or analyze larger networks in segments or with approximate methods. As quantum hardware improves (with increasing qubit counts and better error rates), the range of tractable problem sizes will grow.

Where the quantum approach shows promise against classical tools is in the **quality of solutions and exploring many partitions** quickly. Quantum annealing inherently performs a form of parallel exploration of the solution space by tunneling through energy barriers, which might help avoid getting stuck in suboptimal partitions that trap greedy algorithms. The earlier cited study on power grid networks found that the quantum solver could find as good or better modularity than Louvain for certain partition counts. Hybrid quantum-classical algorithms (like D-Wave's hybrid solvers) have also matched classical solvers on small benchmarks, and they continue to improve. It is important to note that on very small networks, classical brute-force or exact solvers (like Gurobi ILP) can find the true optimum, and indeed, in tests, the classical Gurobi solver was faster (by a few seconds) than quantum/hybrid for small cases. But those classical exact methods become unfeasible as the network grows slightly larger (exponential worst-case complexity), whereas quantum annealing doesn't have the same worst-case explosion for certain structured problems – it might solve some instances faster or at least provide good solutions consistently when classical heuristics vary.

Another aspect is **integration and user experience**. Existing classical community detection tools are standalone algorithms; researchers must know how to apply them and interpret results. NTARI's platform aims to integrate the quantum algorithm into an accessible web-based interface, lowering the barrier to using advanced optimization. This unique combination of quantum backend + user-friendly front-end is relatively novel. There are few, if any, publicly available services where one can "upload your network and run quantum community detection". Some companies and labs have internal prototypes, but NTARI's open-platform approach would democratize this capability.

Hybrid Tools: We note that some hybrid approaches (e.g., running a classical algorithm to seed or post-process the quantum results) will likely be used. The competition is not just quantum vs classical, but how they can complement each other. For instance, NTARI's solution might use a classical algorithm to determine the number of communities or to verify the modularity of the quantum result, creating a feedback loop that ensures the answer is sound. This hybrid approach can mitigate the risk that quantum solvers give a suboptimal or odd result due to hardware noise – the classical check can catch and correct such cases. In the broader landscape, companies like D-Wave offer hybrid solvers that automatically partition large problems and solve parts with quantum and classical methods together. NTARI can leverage such hybrid APIs (for example, D-Wave's Cloud offers a hybrid BQM solver) as part of the backend. The advantage NTARI has is in tailoring the entire pipeline to the domain of social network analysis and making it open and interactive for users interested in community networks.

Unique Advantages and Innovations

NTARI's Quantum Community Detection & SNA Platform distinguishes itself from existing tools through several key advantages:

- **Mission-Driven Design:** Unlike generic network analysis software, this platform is explicitly designed to advance NTARI's mission of collective intelligence. That means features will cater to use-cases like citizen science projects, knowledge-sharing communities, and nonprofit collaboration networks. For example, the platform could integrate with NTARI's **Node.Nexus** (an online repository of collective intelligence research) to map how research entries and contributors cluster by topic. It could also be used in partnership with other civic tech groups to analyze their social networks (e.g., mapping relationships in a community advocacy coalition). By focusing on these applications, NTARI's tool will carve a niche that large commercial software might overlook – the emphasis is on insight and empowerment for communities, not just corporate analytics.
- **Thought Leadership in Quantum Social Science:** Developing one of the first quantum-powered social network analysis tools positions NTARI at the forefront of an emerging field. This visibility can translate into academic partnerships and media attention. NTARI can publish findings from the project, contributing to research on how quantum algorithms perform on social data (an under-explored area). If successful, the project showcases a positive narrative for quantum tech – one that emphasizes ethical and societal benefit, rather than just financial or military uses. This thought leadership could attract talent

(researchers, student interns, volunteers excited about the mission) and further funding. In essence, NTARI can become known as a pioneer of **quantum collective intelligence** solutions.

- **Interactive Visualization and Education:** By integrating visualization of network communities, the platform doubles as an educational tool. Stakeholders will be able to see, for example, how a large online community breaks into sub-groups, which is intuitive and eye-opening. This visual approach helps communicate the value of the analysis to non-experts – a funder or policy maker can immediately grasp what the quantum tool is doing by looking at a graph plot with colored clusters. Such visuals make the abstract concept of "quantum optimization" more concrete ("Here is how our quantum solver grouped these 500 forum users into thematic communities, which a classical approach might handle differently."). NTARI can use these demonstrations in workshops or public talks, aligning with its educational role in demystifying advanced technology.
- **Extensibility for Other Analyses:** While community detection is the initial focus, the platform's architecture (data input → quantum solver → results → visualization) can be extended. Future modules might include quantum algorithms for influence maximization (finding key influencers to spread information) or link prediction (predicting emerging connections in a social network), both of which tie into collective intelligence by identifying how information flows and how collaboration networks evolve. By starting with community detection, NTARI builds a foundation to iterate and add more quantum analytics, keeping the platform relevant over the long term. Each addition would leverage the core infrastructure (user management, data handling, integration with quantum backends) established by the MVP, making subsequent features easier to implement.
- **Public Accessibility and Open Science:** NTARI's nonprofit ethos means the tool will be accessible to the public or at least to a broad community of researchers and citizen scientists, likely as open-source or via a free web interface. This is a stark contrast to most quantum analytics tools, which might be proprietary or behind corporate cloud platforms. Open access allows a global audience to experiment with quantum community detection on their own datasets, fostering a community of practice. Users could share their findings on Node.Nexus, creating a feedback loop where the platform not only serves analysis needs but also feeds new content and case studies back into NTARI's knowledge commons. This aligns with the concept of *digital citizen science*, where citizens are not just subjects but active investigators – here they would use a quantum tool for their community research projects.

Alignment with NTARI's Mission and Impact

This MVP is tightly aligned with all three pillars of NTARI's mission (collective intelligence, digital citizen science, and cooperative internet systems):

- **Collective Intelligence:** The platform directly helps map and strengthen collective intelligence networks. By identifying communities in knowledge-sharing platforms or social media, it reveals the sub-structures of collaborative groups. For instance, using the tool on an open-source project's contributor network might uncover sub-teams or affiliations, knowledge that can improve how the project organizes itself. In NTARI's context, applying it to [Node.Nexus] could show which research themes are emerging and which contributors cluster together, guiding curation efforts. In short, it helps make invisible connections visible, which is key to nurturing collective intelligence (people can then connect better with their peers in the same "cluster" of interest). As one of NTARI's goals is to *"establish overlapping... collective intelligence networks"*, mapping communities is a foundational step toward that goal – it provides the landscape of the networked knowledge ecosystem NTARI is fostering.
- **Digital Citizen Science:** By providing a sophisticated tool in an accessible manner, NTARI empowers citizen scientists to perform analyses typically reserved for well-resourced labs. A local community group could use the platform to analyze a social network of their volunteers or map connections between civic issues and stakeholders. Previously, running a community detection on large data might require technical know-how and computing power; NTARI's platform lowers these barriers. Moreover, because it's novel (quantum-based), it sparks curiosity – citizen scientists engaged in the project also become learners about quantum computing, creating an outreach and informal education opportunity. Yet, NTARI can include tutorials and documentation with the platform to guide non-experts, aligning with its objective to raise public awareness and competence in advanced technologies for social good.
- **Cooperative Internet Systems:** While this MVP is more on the analysis side than directly operating an internet service, the insights it provides can improve cooperative online spaces. Many cooperative digital platforms (like decentralized social networks, knowledge commons, etc.) have governance and community-building challenges. Understanding the community structure within those systems can inform better design – for example, knowing the user communities in a decentralized forum could guide how to allocate moderation resources or which sub-groups to connect with each other for cross-pollination.

Additionally, NTARI's focus on **knowledge networks** and **non-profit alliances** means the platform might be used to map how organizations connect (a meta-network). Identifying clusters of nonprofits working on related issues could facilitate coalition-building. These outcomes support a stronger cooperative infrastructure by using data-driven approaches to foster connectivity and resilience.

Finally, delivering this project will elevate NTARI's profile in the intersection of quantum tech and social innovation, attracting partnerships. Potential collaborators include university network science labs (interested in the quantum angle) and civic tech organizations (interested in the community insights). Such partnerships can amplify NTARI's impact – for example, working with a university could validate the tool on academic co-authorship networks, yielding publishable results, while a civic tech partner might apply it to a grassroots network, yielding practical interventions. This cross-sector relevance – academic and public sector – enhances NTARI's role as a bridge between cutting-edge research and real-world application for community benefit.

Implementation Roadmap and Milestones

Developing the Quantum Community Detection & SNA Platform will involve staged milestones over approximately an 18-24 month timeline, ensuring technical feasibility at each step and integration with NTARI's ecosystem:

- **Phase 1: Feasibility Prototype (Months 1–6).** The goal of Phase 1 is to build a basic working prototype of the quantum community detection pipeline. Key tasks include: formulating the community detection problem for a quantum solver (QUBO formulation of modularity), setting up access to a quantum annealer (e.g., via D-Wave's Leap API or IBM Q for QAOA), and testing the solver on small example networks. We will start with well-known small networks (such as Zachary's Karate Club graph with 34 nodes, or a small subgraph of an online social network) to validate that the quantum backend returns correct community partitions. On the front-end, a simple command-line or notebook interface will suffice initially to input a network and get communities out. A success milestone for Phase 1 is **demonstrating end-to-end quantum community detection on a toy network**, comparing the results with a known classical algorithm to ensure validity. This phase will likely involve one quantum specialist and one network scientist working in tandem to tune the formulation. If quantum hardware is a bottleneck, we will explore hybrid solutions (e.g., D-Wave's hybrid solver that can handle larger QUBOs by splitting work between quantum and CPU).
- **Phase 2: Platform Development and Integration (Months 6–12).** In this phase, the prototype evolves into an interactive platform. We will develop a web-based interface (leveraging NTARI's existing web infrastructure, possibly as an extension of Node.Nexus or a separate portal linked to it). Users should be able to upload network data (in common formats like edge lists or GraphML) or select from sample datasets. The system will run the quantum community detection in the backend (with proper queue management if multiple jobs, and fallbacks to a classical algorithm if the quantum job size is exceeded). Visualization components will be implemented – for example, using D3.js or a Python-based graph visualization that can render results in the browser. Data integration is also addressed here: we ensure the platform can pull data from NTARI's Node.Nexus or other NTARI databases to allow seamless analysis of NTARI-related networks (this might mean writing adapters or APIs between Node.Nexus data and the format needed for the tool). The milestone for Phase 2 is having a **minimal viable web application**: one where a user can perform a full analysis on at least a preset dataset and see the visual community output. Internal testing with NTARI staff and a few friendly external users (e.g., volunteers from NTARI's community) will be done to gather feedback on usability.
- **Phase 3: Pilot and Use-Case Demonstrations (Months 13–18).** With the platform functional, Phase 3 focuses on applying it to real-world use cases to demonstrate value and refine performance. We will identify 2–3 pilot projects. For example: (a) **Node.Nexus Community Map** – use the platform to map the thematic communities within Node.Nexus' content or user base (if user interaction data is available, or co-authorship of entries). (b) **Non-Profit Network Analysis** – partner with a friendly nonprofit or coalition to input their partnership network data and find communities (e.g., an alliance of environmental NGOs to see how they cluster by sub-issue or geography). (c) **Online Community Health** – analyze data from a public online community (perhaps a subreddit or a wiki project, using publicly available interaction networks) to find subgroups and possibly identify which communities are isolated or well-connected. During these pilots, we will likely need to handle larger data sets, so part of Phase 3 is optimizing the pipeline: maybe implementing graph sparsification or smarter splitting of the problem for the quantum solver, to push the limit on network size analyzed. We will also gather outcome metrics – e.g., did the quantum method find meaningful communities that classical methods missed, or how fast did it produce results vs classical? These findings will feed into a report or even an academic paper. A key milestone is the **successful completion of at least one case study with a demonstrable insight or outcome** (for instance, a visualization for the partner that they find useful, or a

comparison showing that the quantum found a higher modularity partition). That will validate the MVP's real-world applicability.

- **Phase 4: Enhancement and Expansion (Months 19–24, and beyond).** After initial pilots, we plan for a phase of improvements based on user feedback and adding features that increase impact. This may include: implementing a more robust job scheduling system for the backend (if many users want to run analyses, handling concurrent requests, possibly queuing or batching jobs to send to the quantum service); improving the UI with features like community metrics, ability to edit or refine communities manually, or run comparative analysis (quantum vs classical side by side); and exploring incorporation of a second quantum algorithm (for instance, an influence maximization module as a beta feature, using a variational quantum solver). We will also address long-term sustainability: documenting the code, open-sourcing it, and training staff or volunteers to maintain the platform. By the end of Phase 4, the MVP should be stable and feature-rich enough to serve as an ongoing NTARI service. At this point, we would officially launch the platform publicly with appropriate communication (webinars, press release to our networks, etc.).

Throughout all phases, we will maintain a close eye on **risks and mitigations**: for example, if early on we find quantum results are consistently no better than a fast classical heuristic on our test cases, we might pivot to emphasize the educational/demo value of the platform (it can still be used to illustrate quantum computing principles, even if not beating classical, which is still a worthy outcome for outreach). We will also address ethical considerations, ensuring that any social network data analyzed is either public or provided with consent, and results are handled with care (since community detection can potentially reveal sensitive groupings, we will include guidance on privacy and ethics in using the tool, in line with NTARI's values).

Estimated Budget and Funding Sources

Developing and deploying this platform will require a combination of technical talent, computing resources, and community engagement efforts. We estimate the following budget for a 2-year development cycle:

- **Personnel:** Approximately **$250,000** total for personnel. This includes a quantum algorithms scientist (possibly part-time consulting if not full-time, budgeted $100k/year including benefits for a half FTE over two years), a full-stack developer to build the platform and visualization ($100k/year for one year), and a part-time community/network science specialist for data and outreach tasks (~$50k). NTARI may leverage volunteer contributions to reduce costs, but we budget for key roles to ensure continuity.
- **Quantum Computing Resources:** About **$50,000** allocated to quantum cloud access and computing costs. While some quantum providers offer limited free access for research, for reliability, we assume purchasing time or credits on a quantum annealer or cloud service (e.g., D-Wave Leap's business plan or IBM Quantum premium access). This cost would cover numerous runs needed for development and user jobs during the pilot phase. We also include some budget for classical cloud computing or workstations for pre-/post-processing and visualization (though this is relatively minor, perhaps $5-10k for cloud server time).
- **Platform Infrastructure: $20,000** for web hosting, storage, and integration. Since NTARI already has some infrastructure, this mainly accounts for any new server instances, database scaling, and security measures needed for hosting an interactive platform with user-uploaded data. It also covers incidental software licenses or APIs (for instance, if we integrate a particular visualization library that isn't free, though most are open-source).
- **Workshops/Dissemination: $15,000** to organize community workshops, user testing sessions, and produce documentation/tutorials. This might include travel or small stipends for pilot partners, hosting webinars for training users, and creating polished materials to help users learn the platform (guides, videos).
- **Contingency: $15,000** (approximately 5-10%) for unforeseen costs, such as higher cloud usage than expected or additional development sprints if something overruns the schedule.

Overall, the budget for MVP 1 is on the order of **$350,000** for two years. This budget is quite modest for a quantum project; NTARI's lean approach and partially volunteer-driven model help keep costs down. Nonetheless, funding is needed, especially for the technical development and computing resources.

Possible Funding Sources: To support this budget, NTARI will pursue a mix of grants and partnerships:

- *Research Grants:* Agencies like the **National Science Foundation (NSF)** (for example, programs in quantum computing applications or Cyberinfrastructure for emerging technologies) are prime targets. An NSF grant could cover the core technical development as a research pilot. Similarly, the **EU Horizon Europe** framework or national funding agencies (if partnering with a university) could fund the research aspects, especially if we position it as advancing the state of the art in network science.

- *Philanthropic and Foundation Grants:* Foundations focused on technology for social good or digital community building are a match. For instance, the **Alfred P. Sloan Foundation** or the **Moore Foundation** has funded open-source scientific tools. Foundations in the digital democracy space (like the **John S. and James L. Knight Foundation** or **Omidyar Network**) might fund a project at the intersection of tech and community well-being. We will highlight how the platform can help understand online communities and information ecosystems, which ties to improving public discourse – a key interest for such funders.
- *Corporate and In-Kind Partnerships:* Quantum computing companies (like D-Wave, IBM, or newer startups) may provide in-kind support such as free or discounted access to their hardware for this non-profit initiative, as it provides them a high-profile use case. We will approach these companies' academic partnership or CSR (Corporate Social Responsibility) divisions. Additionally, tech firms with an interest in graph analytics (for example, enterprise social network analysis firms) might sponsor or collaborate if they see long-term value. However, NTARI will ensure any corporate involvement aligns with our open, public-good orientation (e.g., co-developing open-source code, not exclusive IP deals).
- *Public Sector Tech Initiatives:* There are government and multilateral programs focusing on digital inclusion and innovation. For example, the **U.S. Economic Development Administration** or **Smart Cities initiatives** might support tools that empower communities with data (though MVP 2 aligns even more with smart cities, MVP 1 can be pitched as strengthening civil society networks). Also, **UNESCO's ICT for Education** or **Mozilla Open Science** mini-grants could be small supplementary funding sources to cover things like workshops or documentation efforts.

NTARI will likely pursue a combination of an anchor grant (to cover the bulk of costs) and supplementary grants. The budget and roadmap can be scaled if needed – for instance, if only partial funding is obtained initially, we would stretch Phases 1 & 2 over a longer period using volunteers and seek additional funds after demonstrating the prototype.

By clearly articulating the social benefits and the innovative nature of this platform, we are confident in securing the necessary support. The next section of this white paper discusses the second MVP, the Quantum Network Flow Optimizer, which has a different technical focus but a similarly strong alignment with NTARI's mission and an implementation plan for impactful outcomes.

MVP 2: Quantum Network Flow Optimizer for Cooperative Internet Systems

Technical Overview

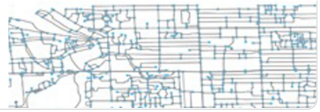
Modern internet systems and civic infrastructures often involve complex networks through which resources – data packets, vehicles, electricity, etc. – must flow efficiently. **Network flow optimization** is a class of problems where the objective is to find optimal paths or distribution of flow through a network to improve some metric, such as minimizing congestion, travel time, or cost, subject to constraints (like capacity limits on links). In a cooperative internet context, we can think of scenarios such as: routing data in a community mesh network so that bandwidth is fairly allocated and latency is minimized, or planning traffic light patterns in a city grid to reduce jams and emissions. These are fundamentally graph problems with many variables and constraints, often NP-hard when formulated in full generality (for example, the multi-commodity flow problem or time-dependent routing are NP-hard).

Quantum Approach: The Quantum Network Flow Optimizer aims to harness quantum algorithms to tackle these challenging routing and flow problems. The approach varies depending on the specific use case, but generally involves formulating the optimization as a form of combinatorial problem suitable for quantum solvers. One common method is to express the routing problem as a QUBO (similar in spirit to the community detection approach, but with a different objective function). For example, consider a simplified routing problem: find the optimal path for a packet from source to destination that minimizes congestion. We can discretize possible paths and use binary variables to indicate which route is chosen; additional variables can represent congestion on each link. A cost function is defined that penalizes high congestion and perhaps path length, and the quantum annealer tries to minimize that cost. More complex, a quantum optimizer can handle multiple flows simultaneously by encoding each flow's path variables and adding coupling terms to ensure they don't all crowd the same link (thereby distributing traffic).

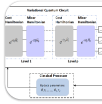
Frontiers | Traffic Flow Optimization Using a Quantum Annealer

Quantum annealing algorithms belong to the class of metaheuristic tools, applicable for solving binary optimization problems. Hardware implementations of qua...

Frontiers



An alternative approach is using **QAOA on a gate-based quantum computer**: by constructing a problem Hamiltonian that encodes, say, the constraints of routing (each flow must start and end at certain nodes, conservation of flow at intermediate nodes, capacities not exceeded), one can use QAOA to find low-energy states that correspond to good routing plans. Recent research demonstrated QAOA finding optimal paths in small network routing problems – in one study, a QAOA formulation converged to the optimal route in a 6-node graph within 25 iterations. This indicates that even with just a simulator or a few-qubit real device, one can correctly encode and solve short pathfinding tasks.



Quantum Approximate Optimization Algorithm for Routing Optimization in 6G ...

The key point is that **quantum optimization can evaluate many routing combinations simultaneously**, and for certain sizes, it may explore the search space more effectively than classical heuristics, which navigate sequentially. A real-world example comes from telecommunications: NTT Docomo in Japan used a D-Wave quantum annealer in a hybrid mode to optimize paging channel assignments in their cellular network. The result was a *15% reduction in paging signals during peak hours*, allowing 1.2× more devices to connect concurrently, and the quantum solution was obtained in 40 seconds versus 27 hours with a classical approach.

Quantum Optimization Improves Mobile Network Performance by 15%

Updated on Aug 21, 2024

This data determines the best combination of base stations to re-establish connections as devices move between tracking areas

IOT World Today

This dramatic speed-up and improvement show the potential when a combinatorial telecom problem is mapped well to a quantum annealer.

For NTARI's MVP, the primary focus is on **cooperative internet systems** – networks that are community-run or aimed at public benefit rather than profit. Examples include community mesh Wi-Fi networks, local ISP cooperatives, municipal broadband, or even data-sharing networks between civic centers. These networks often operate under constrained resources, so optimizing flow can greatly enhance their performance (e.g., maximizing coverage or quality of service with limited bandwidth). The quantum optimizer will target problems like: optimal routing tables for a wireless mesh (which links should carry what portion of traffic to avoid overloading any one node), or optimal placement of cache servers in a network to minimize long-distance data fetches. It could also extend to transportation cooperation: for instance, optimizing routes for a community rideshare or delivery service, which echoes the aforementioned DENSO case of optimizing taxi schedules with quantum annealing.

How will the optimizer work in practice? Users (likely network operators or researchers) will input parameters of their problem. For a mesh network, input might be the graph of connectivity with capacities and current demands between nodes; for a traffic system, it could be a traffic network graph with source-destination pairs of vehicles. The system will translate this into an optimization model. If using an annealer, it sets up the QUBO with variables representing key decisions (e.g., an edge is used by a route or not) and with penalty terms for violating constraints (like exceeding capacity). If using a gate-based approach, it constructs the equivalent circuit and runs the variational algorithm. The output from the quantum solver is a set of decision variables (like which route each flow takes). The platform then interprets this into a user-friendly result: a set of recommended paths or a flow distribution scheme. A visualization might highlight the chosen routes on a map or network diagram for clarity, as illustrated in Figure 2 (which conceptually shows an example network with two alternate routes and the optimizer's chosen path):

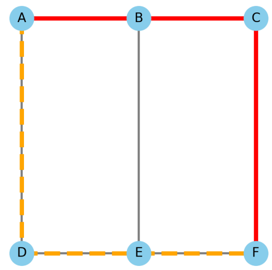


Figure 2

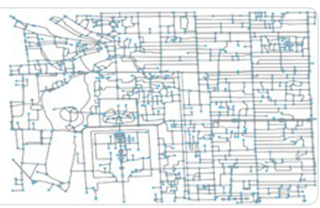
Figure 2: Illustration of a network flow optimization scenario. In this simple network, a source at node A must send data to node F. There are two main route options – one along the top (A–B–C–F) and one along the bottom (A–D–E–F). The quantum optimizer evaluates possibilities and selects the optimal path (shown in solid red) that minimizes congestion or distance, as opposed to the alternate (orange dashed) route. In a real network, the optimizer would handle many sources and destinations simultaneously, finding an overall flow assignment that best meets the objectives.

The technical challenge in building such an optimizer is significant: network flow problems often involve many variables and constraints, which can be hard to map directly onto current quantum hardware. One strategy is to focus on a specific formulation that is amenable to available quantum resources – for example, a *binary decision version* of the flow problem (each link either is or isn't used by a flow) rather than a fully fractional flow, which is more naturally a linear programming problem. By using binary simplifications, we can leverage quantum annealers, which solve binary optimization natively. This might require creative tricks, like splitting the flow into small units or using multiple binary variables to approximate quantities. NTARI will leverage known formulations from operations research and prior quantum studies to guide this. For instance, D-Wave published examples of traffic flow optimization where car route assignments were optimized by minimizing overlapping routes, implemented with a series of quantum calls in an iterative workflow. We can draw from such methodologies to design our solution.

Frontiers | Traffic Flow Optimization Using a Quantum Annealer

In this paper, we will introduce the traffic flow optimization problem. We start with the T-Drive trajectory data set1 of cars’ GPS coordinates and develop a workflow to mimic a system that aims to optimize traffic flow in real time. We show how to...

Frontiers



Comparison to Classical Solutions

Classical Network Optimization: Traditionally, network flow optimization is tackled with techniques like linear programming (for fractional flow problems) or mixed integer programming (for routing with discrete choices). For simpler cases like single-source single-destination shortest path, we have efficient algorithms (Dijkstra's algorithm, etc.). But for multi-source, multi-destination with interference (e.g., traffic where each car's route affects others' travel time), the problem becomes complex. Traffic assignment in transportation often uses iterative methods (like the Frank-Wolfe algorithm for user equilibrium) or agent-based simulation plus heuristics. Routing in data networks (like Internet routing protocols) typically uses distributed algorithms that find shortest paths independently, and then engineers have to adjust weights or add rules to handle congestion, which is suboptimal globally. There are also meta-heuristics like genetic algorithms or ant colony optimization that have been applied to network routing problems.

Classical solvers like Gurobi can, in theory, solve the integer programming formulation of these problems, but for any reasonably large network, the number of possible route combinations is enormous, and the search explodes. Indeed, in the earlier Docomo example, a classical approach took 27 hours for a scenario that the quantum approach handled in seconds. That classical approach likely was doing a brute-force search or heavy computations on a large state space (the paging problem can be seen as a combinatorial optimization of regions). This highlights that there are practical cases where classical methods either fail to find the optimum in a useful time or at all (they might rely on heuristics that give okay solutions, but not the best).

Quantum Optimization Improves Mobile Network Performance by 15%

Updated on Aug 21, 2024

connections as devices move between tracking areas

IOT World Today

Quantum vs Classical: The promise of the quantum network flow optimizer is to potentially find better solutions for these hard cases or find good solutions faster. In scenarios where classical algorithms are near optimal (e.g., simple networks or linear programming relaxations), the quantum approach might not show much benefit. However, as complexity grows, quantum's ability to sample a huge solution space in superposition could find novel routing configurations that classical methods miss. The DENSO case is a concrete illustration: a quantum-assisted algorithm coordinated 400 taxi trips with 30% fewer vehicles than the conventional scheduling method required. This suggests the quantum method found a clever way to share taxis among trips that the heuristic dispatcher did not. Achieving such a reduction is very significant in transportation (fewer vehicles for the same service means cost savings and lower emissions). Similarly, in a network scenario, a quantum optimizer might, for example, route traffic in a pattern that balances load in a non-intuitive way, reducing peak congestion by, say, 20% compared to standard routing – a benefit that translates to faster internet speeds or more stable service for users.

Using quantum to make the future of urban transportation faster, smoothe...

It is important to temper expectations: current quantum hardware is still limited, and for many flow problems, a purely classical approach or even simple greedy heuristics might outperform if the problem size exceeds the quantum capacity. One possible outcome is that the quantum optimizer will excel in **medium-scale instances with high complexity**, whereas for very large networks, we may end up using a hybrid solution. For example, we might decompose a city-wide traffic problem into regions, use quantum optimization on the most congested subnetwork (where the hardest decisions need to be made), and use classical methods elsewhere. This hybrid strategy acknowledges that quantum is not a silver bullet but can be inserted where it adds most value.

Another dimension is **solution adaptability**. Classical solvers usually give one static solution per run; if conditions change (say, a road is closed, or network demand shifts), you have to rerun from scratch. Some quantum algorithms, by contrast, could potentially adapt faster. Quantum annealing, for instance, can be reinitialized with a new problem matrix quickly, possibly finding a new solution in seconds for the updated scenario. If integrated into a control loop, a quantum optimizer might adjust network settings in near-real-time. This was hinted by the Docomo use-case, which was about dynamic network management – quantum was used in what could become a feedback mechanism for live telecom networks. NTARI's optimizer, if successful, could pave the way for *real-time adaptive optimization* in community networks: imagine a mesh network that continuously tunes its routing as users join or leave, using a quantum solver in the cloud every few minutes to re-optimize routes. Classical methods might not keep up if they take hours to compute a new solution, whereas a quantum approach might deliver updated optimizations on the fly (this is speculative but worth exploring in design).

Quantum Optimization Improves Mobile Network Performance by 15%

Updated on Aug 21, 2024

The companies used D-Wave's annealing quantum computing product as part of a hybrid quantum solution to reduce congestion at base stations in the Tokai, Chugoku and Kyushu regions

IOT World Today

Existing Tools and Competitors: At present, there are few, if any, public quantum tools for network flow, since it's cutting-edge research. Some companies have prototypes (D-Wave has showcased traffic flow and satellite scheduling examples), and academic groups have simulated QAOA for routing. On the classical side, large vendors offer optimization suites (like IBM CPLEX, Gurobi), but these are generic solvers, not tailored for cooperative networks and not user-friendly for non-experts. There are also specialized simulation tools for traffic (SUMO, MATSim) and network planning (GraphPlan, etc.), but these typically don't incorporate quantum capabilities. NTARI's solution, by focusing on the community use case, stands out as likely the **first application of quantum optimization in the community network / civic tech domain**. That uniqueness is an advantage when seeking support – it's a novel approach that, if demonstrated, others will likely follow, but NTARI can have a first-mover advantage and establish expertise in this niche.

Unique Advantages and Value Proposition

The Quantum Network Flow Optimizer brings several unique advantages that align with NTARI's values and the needs of cooperative networks:

- **Empowering Underserved Networks:** Cooperative and community networks (like rural broadband cooperatives or city-run transit systems) often lack access to cutting-edge optimization that big corporations enjoy. By developing a quantum-based solution and focusing it on these contexts, NTARI provides a leapfrog opportunity – these smaller players could harness state-of-the-art tech to vastly improve their services. It's a form of technological leapfrogging: similar to how some developing regions skipped landlines and went straight to mobile, here, community ISPs might skip investing in massive computing clusters and utilize cloud quantum solvers to optimize their network. This fulfills a social equity angle: ensuring that the benefits of quantum computing are not restricted to large telecoms or tech giants, but rather shared with grassroots and public sector initiatives.
- **Demonstrable, Tangible Impact:** Network flow optimizations yield results that can be measured in the physical world – e.g., internet throughput, latency, travel time saved, etc. This makes the success of the MVP easy to communicate. If a pilot shows, for instance, that a community mesh network increased its data throughput by 15% using the optimizer, or a city reduced average emergency vehicle travel times by 10% on optimized routes, these are compelling statistics for stakeholders. Such concrete improvements (faster Wi-Fi, less traffic) resonate with the public and policy makers, more so perhaps than the more abstract community-detection insights of MVP1. Thus, this project can be a flagship example of quantum tech delivering *practical public benefit*. It also addresses pressing societal issues: improved internet connectivity and smarter transportation are priorities in many communities.
- **Synergy with NTARI Programs:** NTARI has existing programs like Forge Lab (for open innovation) and Mesh Grants (supporting community networks). This MVP can directly plug into those. For example, NTARI could offer the optimizer tool as a service or in-kind support to winners of Mesh Grants to enhance their network deployments. It could also be a centerpiece of Forge Lab hackathons, where volunteers and partners come together to extend the tool or apply it to new scenarios. This synergy ensures the MVP isn't an isolated R&D project but integrated into NTARI's ecosystem, multiplying its impact. Every community network NTARI engages with becomes a potential testbed and beneficiary of the quantum optimizer, creating a virtuous cycle of development and real-world application.
- **Innovation in Methodology:** From a technical standpoint, the project pushes the envelope in formulating flow problems for quantum machines. This means NTARI's team will likely come up with novel formulations or hybrid algorithms, contributing intellectually to the field of quantum optimization. Publishing these methods can raise NTARI's research profile. Also, by focusing on a specific niche (community networks), NTARI might solve special cases more efficiently than general solvers. For instance, community mesh networks often have planar graph structures (if they're based in neighborhoods) or certain regularities – NTARI can exploit that in the model to reduce complexity. This kind of tailored innovation is something big, generic efforts might overlook. It's an opportunity to be the **go-to expert in quantum optimization for "small networks, big impact" scenarios**.
- **Future Extensibility:** Much like the first MVP, the network flow optimizer can be extended beyond internet data. The core techniques would apply to other flow-like problems that nonprofits encounter: e.g., humanitarian logistics (optimizing delivery of supplies), optimizing energy flow in community microgrids, water distribution in smart irrigation systems, etc. By developing a core solver for routing, NTARI sets the stage to tackle these related problems. This means the investment in this MVP can lead to a family of applications, each appealing to different funders (for instance, a foundation interested in climate resilience might fund adapting the optimizer to energy grid use). This extensibility increases the ROI of initial development – the algorithms and software can be repurposed with relatively small changes for multiple social good applications.

Alignment with NTARI's Mission

The network flow optimizer MVP is a direct expression of NTARI's commitment to **cooperative internet infrastructures** and also intersects with collective intelligence and citizen science:

- **Cooperative Internet Systems:** This is the core. By improving the performance and resilience of community-run networks (whether that's a local mesh providing free Wi-Fi or a cooperative broadband ISP in a rural area), the MVP strengthens the foundational infrastructure that NTARI believes should be democratized. A cooperative internet thrives when communities can self-manage their network resources effectively. The optimizer is a tool for smarter self-management. It enables small network operators to achieve efficiency gains that typically only big telecom companies (with large R&D divisions) could, thus leveling the playing field. This helps fulfill NTARI's vision of a world where connectivity is not controlled by monopolies but by communities in collaboration, because those communities will now have access to top-tier optimization tech to run their networks optimally. We can imagine, for example, a consortium of community networks coming together via NTARI to collectively use this optimizer for their various networks, sharing knowledge and perhaps collectively purchasing quantum cloud time – a very tangible realization of cooperative infrastructure enhancement.
- **Collective Intelligence:** On the surface, routing might seem more infrastructure than intelligence, but collective intelligence also involves how groups coordinate and solve problems. Traffic systems and communication networks can be seen as collective systems where many agents (drivers, data packets, users) must self-organize. The optimizer effectively injects a higher-level intelligence into these systems by finding patterns that reduce conflict (like two flows competing for the same road). One could say it augments the collective intelligence of, say, all drivers in a city by giving them optimized routes that collectively minimize jams. In a community network, the collective behavior of data flows becomes more efficient. Additionally, developing the optimizer will involve collective effort – e.g., engaging citizen scientists or local network admins in providing data and feedback. Those stakeholders become part of the R&D, learning from the process (which is an expression of collective problem-solving). So in practice, this project can galvanize a community of practice around quantum optimization for local problems, effectively *crowd-sourcing intelligence* on how to run networks better, powered by the tool NTARI provides.
- **Digital Citizen Science:** There is an opportunity to involve tech-savvy citizens in the development and use of this optimizer. For instance, members of amateur radio mesh networks or civic tech meetups could contribute real data and test scenarios, essentially participating in an experiment to improve their own community's connectivity. This participatory approach turns the MVP into a citizen science project, where local knowledge (like where congestion occurs, or what user needs are) feeds into the model design. NTARI could host open challenges or data hackathons where citizen scientists use the optimizer to solve a problem (e.g., a challenge to optimize traffic flow for an event in town, using simulated data). By doing so, we also demystify quantum tech, taking it out of the laboratory and into the hands of ordinary people working on everyday problems. The curiosity and learning that occur aligns well with digital citizen science goals – it's a novel way to get citizens involved in scientific research (quantum computing + network science) with direct application to their community.

In sum, MVP 2 is at the heart of NTARI's mission because it directly works on improving **connectivity and resource-sharing networks for the public good**. The internet and transportation networks are like the veins of modern society; making them more efficient and equitable via advanced tech is both a social benefit and a statement that futuristic tech (quantum) can be harnessed for public interest outcomes. This narrative is powerful for policy advocacy as well: it shows policymakers that investing in community tech doesn't mean settling for "low-tech" solutions – communities can handle high-tech tools and produce innovations when given the opportunity.

Implementation Roadmap and Milestones

Developing the Quantum Network Flow Optimizer will likely be a multi-phase project over roughly 2 years (similar to MVP1, though some phases might need more time due to complexity). Key phases and milestones include:

- **Phase 1: Problem Scoping and Prototype Design (Months 1–4).** In this initial phase, the team will narrow down the specific flow problem to tackle first and design the quantum formulation. We will conduct a needs assessment with potential users (e.g., interview a community network operator or review typical problems faced by mesh networks). Suppose we decide the first use case is optimizing routing in a wireless mesh network. We will formalize that: for example, given a graph of wireless nodes with certain demand between pairs, how to route the packets. Next is formulating this as a QUBO or similar. This requires translating network flow constraints into quadratic terms – a non-trivial step that will involve our quantum scientists and network engineers brainstorming and perhaps referencing academic literature. We may consider a simpler subproblem like finding disjoint paths (which is a proxy for load balancing). A milestone at the end of Phase 1 is a **mathematical model and small-scale prototype algorithm** (perhaps in a Python script) that can take a tiny test network (say 4 nodes, 1 flow) and solve it via a quantum solver or even brute force (to verify the concept). Also, by this time, we'll choose the quantum platform (annealer vs gate model or both) to use moving forward, based on which fits the problem best.

- **Phase 2: Quantum Algorithm Implementation (Months 5–10).** In this phase, we implement the chosen formulation on actual quantum hardware or simulators. If using D-Wave, this means writing the code to construct the QUBO and send it to the annealer, and retrieving results. If using QAOA, write the circuit in Qiskit (for example) and run it on a simulator or small quantum processor. We will test with incrementally larger network examples (maybe start with 5-6 nodes, 2-3 flows, then 10 nodes, etc.) to see how the solution quality and time scale. It will be crucial to also have a baseline classical solver to compare (maybe a simple ILP solved by CPLEX or an open-source MILP solver) to ensure our quantum approach is finding good solutions. We expect at this stage to iterate on the formulation – for example, if the results are poor, adjust the penalty weights in the QUBO, or try a different encoding of paths (we might try a direct encoding vs a flow-based encoding and see which yields better results from the quantum solver). A milestone for Phase 2 is the **successful optimization of a moderate-size synthetic problem**: e.g., routing 3 flows in a network of 8 nodes with a better objective value (less congestion) than a naive routing. Another milestone could be demonstrating that the quantum solver can obtain a result within a certain time (say, under 1 minute), which would be encouraging for real-time use.
- **Phase 3: Software Integration and Tool Development (Months 8–14, overlapping with Phase 2).** As the algorithm works progresses, we also start creating the software interface around it. This will involve developing an input/output specification, so that a user can describe their network and demands in a simple format (maybe a JSON file or a small UI form). We'll build a basic interface (likely a web dashboard or a command-line tool initially) where the user can upload network data. The tool will run the optimizer (calling the quantum backend) and then return results. We plan to include visualization for this MVP too, though it might be more domain-specific: e.g., plotting the network graph with thicker lines on chosen routes, or outputting a table of recommended routing decisions. Since network operators might prefer textual results (like a routing table), we will format the output in a useful way. Security and integration considerations: if we partner with a community network, we might have to anonymize or simulate data for privacy. The Phase 3 milestone is having a **prototype software tool that NTARI staff can use on real data sets in a test environment**. For instance, by month 14, we could take a topology of a community mesh (with permission) and run it through our tool to get a routing suggestion, with results viewable on a map.
- **Phase 4: Pilot Deployment with Partners (Months 15–20).** This is where we take the optimizer into a real operational context. We will identify at least one pilot partner – possibilities include: a city transportation department for traffic optimization on a set of streets (maybe starting with something contained, like optimization of traffic flow for a public event or a particular district), or a community wireless network group for routing internet traffic. With the partner, we will set up the optimizer to run on their scenario. This might initially be offline analysis (we take their data, run the optimization in our lab, and give them recommendations). Eventually, we could try an online pilot (e.g., during a specific week, we provide live suggestions and see if implemented). Measures of success will be collected: Did travel times reduce? Did network throughput improve? We will also gauge the user experience: was the tool easy for them to use or understand? A major milestone is **documented improvement in a key metric through the optimizer**. For example, "Using NTARI's quantum optimization, City X reduced average bus route overlap by 15%, cutting wait times by 10%," or "Community Network Y increased its peak data delivery by 20% after reconfiguring routes with NTARI's optimizer." Even a simulated result could suffice if direct implementation is not possible (sometimes, traffic pilots use simulations for safety). We want a clear validation that the approach works in a realistic setting.
- **Phase 5: Refinement, Scaling, and Knowledge Transfer (Months 21–24).** After the pilot, we will refine the tool with lessons learned. Perhaps we found the need for a better user interface or additional constraints (the partner might say, "we also need to account for link reliability, not just capacity"). We'll incorporate such tweaks. We will also work on scaling up the scenarios if possible: try to push to larger networks by using hybrid methods or optimizing code. For instance, if our pilot was on a 10-node network, can we handle 20 or 30 nodes now? This might involve using a hybrid solver or splitting flows into batches. By the end of this phase, the MVP should be a robust beta product that NTARI can maintain and offer. Another important aspect here is documentation and training materials, as we'll want to share the knowledge. We'll likely produce a technical report or even a paper describing the project, and a user manual for future users. We also plan a dissemination event – e.g., a public demo day or a webinar with the pilot partner presenting the results, to attract interest from other communities. The final milestone is a **public release of the optimizer tool (beta)** and at least one endorsement or case study from a pilot partner that we can showcase in NTARI's communications.

Throughout development, we will be mindful of technical risks: for example, if quantum hardware availability becomes an issue (queues too long, or changes in cloud access), we'll have alternative providers or simulate with software when needed (though simulation of large QUBOs is slow, it might help in a pinch for development). We'll also keep an eye on the fast-evolving quantum computing landscape – if better algorithms or hardware come out during the project, we'll evaluate adopting them. The modular approach (separating problem formulation from solver execution via an API) will allow flexibility, e.g., switching from one quantum backend to another if needed, with minimal changes in the pipeline.

Estimated Budget and Funding Sources

The budget for the Network Flow Optimizer MVP is projected slightly higher than MVP1, reflecting the complexity of the problem and the need for more intensive collaboration with external partners. We estimate roughly **$400,000 over two years** for development and pilot implementation. A breakdown:

- **Personnel:** About **$300,000**, covering a dedicated quantum optimization researcher (2 years, ~$120k total), a software engineer (2 years, ~$120k total, since the tool development and integration will be ongoing), and part of a project manager's time plus domain experts (e.g., a network engineer or traffic engineer consultant for short periods, ~$60k). This accounts for the need to interface with external partners (which can be time-intensive) and to iterate on complex algorithm development.
- **Quantum and Classical Computing Resources:** Estimated **$50,000** for computational costs. This MVP may require more experimentation per problem instance (multiple runs to fine-tune solutions), so quantum cloud usage might be higher. Also, we might need to invest in some classical optimization software or high-performance computing to benchmark against (like a Gurobi license or extra cloud CPUs for simulations).
- **Partner Support and Pilot Expenses:** Around **$30,000** earmarked for supporting pilot deployment. This could include hardware or sensors for the pilot (e.g., if we need to set up additional monitoring in a traffic pilot, or provide a beefy server at the community network to interface with our cloud calls), as well as possibly modest subgrants or MOUs with partner organizations to compensate their staff for time spent on the project. If travel is needed to the pilot site for setup and evaluation, it comes under this category as well.
- **Workshops/Community Engagement: $10,000** for events such as hackathons, training sessions with network operators, or a final showcase event. We want to build a user community around the tool, so we'll invest in outreach activities – maybe co-host a session at a relevant conference (like a Community Networks summit or a Smart City expo) to share the results.
- **Contingency: $10,000** for unexpected needs (as before, but perhaps even more crucial here given uncertainties in partner availability and hardware).

Total: ~$400k. If budget needs to be reduced, one approach would be to limit the scope of the pilot (perhaps simulate partner data instead of full deployment) or rely more on volunteer contributions for software development (though the complexity suggests we'd want paid, accountable staff for core pieces).

Potential Funding Sources:

- *Smart Cities and Infrastructure Grants:* Given the nature of this MVP, agencies that fund smart city tech or internet infrastructure could be targeted. For example, the **U.S. Department of Transportation (DOT)** has had programs for advanced transportation technologies that might fund a traffic optimization pilot. The **National Science Foundation** has a Smart and Connected Communities track that would find this relevant, especially if partnered with a municipality (pairing fundamental research with community deployment). Also, **NSF's Quantum Computing Application** initiatives might co-fund us if we highlight the novel quantum aspect in a real community setting.
- *Telecom and Tech Industry Grants:* Large telecom companies or equipment makers sometimes have innovation funds or CSR initiatives for community connectivity. For instance, **Cisco Foundation** or **Google's philanthropic arm** [Google.org: Google's philanthropy] which has funded urban innovation and internet access projects. We could propose our optimizer as a way to improve connectivity equity, which might appeal to them. The partnership with a city or community network in the pilot can strengthen such proposals (they like to see on-the-ground application). Cloud providers (AWS, Azure) also have grants for research; since we might use their infrastructure, we can apply for credits or support there.
- *Foundations Focused on Environment/Climate:* An angle here is that better network and traffic optimization has environmental benefits (reduced energy use, lower emissions from less idling vehicles). Organizations like the **ClimateWorks Foundation** or **Bloomberg Philanthropies** (which funds city sustainability) might support a project that reduces carbon footprint via traffic optimization. If we emphasize the environmental and efficiency outcomes, we can broaden the pool of potential funders beyond just tech-focused ones.
- *Academic and Research Collaborations:* We might secure cost-sharing through collaboration with a university (they might get a government research grant that covers some student researchers on the project, for instance). If a professor in network

engineering finds this interesting, they could co-lead and tap into academic funds, reducing NTARI's burden. Likewise, national labs or research institutes focusing on quantum computing might contribute resources or funds if they see this as a testbed for their algorithms (for example, Los Alamos or Oak Ridge have quantum computing research – perhaps they'd like to collaborate on the method development in exchange for covering some expenses).

- *Municipal/Regional Innovation Challenges:* Some cities or regions have innovation challenges or budgets for new technology pilots. If we partner with a city for the traffic use-case, that city might allocate some funds or in-kind support (like staff time, or integration with their systems, which has value). We will explore if our pilot city (once identified) has any internal funding or could commit to sustaining the project after the grant. That helps show funders that there's local buy-in.

In pursuing funding, we will emphasize the dual nature of the project: it is both **advanced research** (quantum optimization) and **community innovation** (solving real problems). This duality allows us to tap into both science funding and civic tech funding. Also, after initial development, if the optimizer proves valuable, there is potential for modest revenue or cost-recovery by offering it as a service to municipalities or cooperatives (a social enterprise model). While revenue is not the primary goal, mentioning sustainability models could assure funders that NTARI is exploring ways for the project to live on beyond grant support (e.g., maybe a consortium of community networks collectively maintains the tool with membership fees, etc., after we demonstrate it).

To summarize the funding outlook, we are optimistic that the high relevance of this MVP to pressing issues (digital equity, smart infrastructure), combined with the exciting quantum angle, will attract a mix of support. The budget is reasonable for a pilot that could have transformative results, and we will leverage partnerships to maximize in-kind contributions and minimize duplicative costs. The final section concludes the white paper and recaps how these two MVPs position NTARI for leadership at the nexus of quantum computing and network-enabled collective intelligence.

Conclusion and Next Steps

NTARI's focus on the **Quantum Community Detection & SNA Platform** and the **Quantum Network Flow Optimizer** represents a strategic bet that quantum computing can be steered toward solving human-centered, cooperative problems today, and not just in the distant future. By grounding these MVPs in tangible use cases – understanding online communities and improving local networks – NTARI ensures that its research and development efforts yield immediate value for society while also contributing to the longer-term evolution of technology.

In this white paper, we have detailed the technical foundations of each project, showing that they are built upon sound principles of network theory and emerging quantum algorithms. We have compared them to classical approaches, acknowledging the strengths of existing methods but also highlighting where quantum techniques offer a complementary edge (for instance, finding higher-modularity partitions in complex networks, or computing network optimizations that classical solvers would take too long to find). The unique advantages of NTARI's approach lie in our mission-aligned design: these tools are not technology for technology's sake, but rather carefully tailored to empower communities, researchers, and cooperative initiatives – a niche often neglected by commercial tech development.

The implementation roadmaps provided show that these projects are **feasible and broken into achievable milestones**. Early phases focus on prototypes and proof-of-concept (de-risking the quantum aspects on small scales), mid phases integrate those concepts into user-facing platforms, and final phases pilot them in real-world settings to demonstrate impact. This phased approach means funders and stakeholders will see progress at each step, with opportunities to course-correct as needed. Importantly, by the end of the development cycles, NTARI will deliver operational tools: a community detection platform available for broad use, and a network optimizer tested in the field, both accompanied by learnings and likely scholarly outputs.

Budget estimates around a few hundred thousand dollars per project are **cost-effective given the innovation involved**. We have identified multiple synergistic funding avenues, reducing reliance on any single source. This diversified strategy improves the resilience of the projects' financing. Moreover, both MVPs have built-in potential for future expansion (technically and financially): their utility could attract ongoing support from user communities or new partnerships (for example, other nonprofits adopting the platforms, or educational institutions using them for training, contributing improvements in return).

NTARI's broader mission will be materially advanced by these MVPs. Successfully mapping knowledge communities with quantum tools will enhance how we harness collective intelligence on platforms like Node.Nexus, informing better collaboration strategies. Likewise, optimizing cooperative networks will strengthen the digital infrastructure of communities, making the internet more inclusive and efficient. In tandem, these efforts reinforce a narrative that **collective intelligence and cooperative systems**

benefit greatly from cutting-edge research – a narrative NTARI can champion in academic, public, and philanthropic forums. As a result, NTARI will not only deliver useful products but also solidify its role as a pioneer at the crossroads of quantum technology and social innovation.

Next Steps: With this white paper as a guiding document, NTARI will move into the action phase. The immediate next steps include: assembling dedicated project teams and advisory groups for each MVP (ensuring we have the right mix of quantum expertise, network domain knowledge, and community representatives), securing seed funding to kick off Phase 1 work, and formalizing partnerships for pilot sites (initiating conversations with candidate communities, cities, or organizations to collaborate on real-data testing). We will also set up an internal monitoring and evaluation framework to track progress against the stated milestones, which will be reported to stakeholders regularly.

NTARI invites **funders, academic partners, and public sector innovators** to join us in this endeavor. By contributing resources or expertise, stakeholders can be part of a groundbreaking effort that not only pushes the frontier of technology but does so in service of society. We plan to hold a roundtable with interested partners to refine project scopes and incorporate external input, ensuring that the MVPs are tuned to actual needs on the ground.

In conclusion, the two MVPs outlined are ambitious yet achievable projects that exemplify NTARI's ethos of marrying advanced science with cooperative principles. They promise to deliver practical tools with immediate benefits and to pave the way for a new domain of applications where **quantum computing amplifies collective intelligence and community resilience**. Through careful planning, strong partnerships, and unwavering focus on our mission, we are confident that these initiatives will succeed and inspire further innovation at the nexus of network theory and quantum research. NTARI looks forward to translating this vision into reality and sharing the journey with our supporters and the communities we serve.