AN OPTIMIZED REDUCTION OF ADDITIVE ENERGY CONSUMPTION FOR TRAFFIC SIGNALS USING SUPPRESSED SUPERPOSITION FRAMEWORK

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Abstract

This paper presents an optimized reduction of additive energy consumption for traffic signals using a suppressed superposition framework. This approach combines the improved performance of the superposition framework with a systematic process for suppressing energy usage. By using a mathematical model that eliminates the effect of parametric variations in traffic signals, the proposed method can reduce the energy-cost by suppressing unnecessary superposition consumption which results in an optimized energy consumption in traffic signals. The method isolates unique parameters of each signaling experience to reduce unnecessary overlay energy costs and provide precise reductions in total energy consumption. This framework leverages the mutual information between traffic light sources and their corresponding targets, further reducing the additive energy consumption of traffic lights. In addition, a model-prediction-based broadcasting scheduling approach is proposed to reduce the number of broadcasts for each traffic light. It also presents an evaluation of the model in terms of energy savings, code reliability, robustness, and scalability. The proposed method outperforms the traditional approach in terms of efficiency and simplicity that makes it more suitable for large-scale traffic signal control in urban areas.

Keywords: optimization, reduction, energy, consumption, traffic-signals, superposition, framework.

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1. Introduction

The vast amount of energy consumed by traffic signals largely contributes to our global warming problem. Traffic lights are one of the most efficient and widely used methods of traffic control, offering improved road safety for drivers, pedestrians, and cyclists. However, as the number of traffic signals continues to increase, so does their energy consumption. Although traffic signal systems are necessary for preventing collisions and manage traffic, they require large amounts of electricity consumption. The power required to operate a typical traffic controller for one hour is estimated to range from 9.6- 20.8 kWh (kilowatt hours). This energy consumption must be supplied either through the grid, or, increasingly, via renewable energy sources. Significant steps can be taken to prioritize increased energy efficiency and conservation when managing traffic signals, by implementing technologies such as motion sensors, intelligent traffic systems, traffic demand optimization, and signal re-timing. The retrofitting existing traffic signals with more efficient LED lighting bulbs can greatly reduce their energy consumption. Utilizing LED lighting technology can significantly reduce energy consumption by upwards of 70%, hence producing greater energy savings and a reduced environmental impact. Batteries, solar and wind power sources offer alternative clean and renewable energy sources for traffic signals. While these technologies aren't always feasible everywhere, they should be the primary focus in remote locations where the power grid cannot be accessed. The evaluating processes such as signal sequencing, phasing, and timing could further reduce energy use by the traffic signals. The traffic signals can be a significant source of energy consumption, and their energy efficiency must be prioritized in order to reduce our impact on the environment. By implementing efficient LED lighting bulbs, intelligent traffic systems, renewable energy sources, and signal re-timing and sequencing changes, traffic signals can be run with greater energy efficiency and contribute much less to our global warming problem. The recent innovations in energy consumption for traffic signals have been remarkable. Traffic signals can be powered by solar power, wind power, and even geothermal energy. The solar power is the most cost-effective option, since it doesn't require additional energy sources and can provide power for many years. Wind power can be used to supplement solar power, and geothermal energy can be used to power the circuits that control the traffic signals. Solar-powered traffic signals have become increasingly popular in recent years. These systems can store energy from the sun during the day so that the signals remain lit at night. Some systems use sensors to detect approaching traffic and adjust the signal accordingly, saving energy. Others utilize motion sensors to detect the presence of cars and trigger the signal to illuminate. Solar traffic signals can also be fitted with lights that are triggered by ambient light levels or in response to the time of day. The use of wind turbines to power traffic signals is also becoming increasingly popular. Wind turbines are a renewable energy source, and they can provide continuous power for traffic signals without the need for additional energy from external sources. Wind-powered traffic signals are equipped with automatic sensors that detect wind magnitudes and turn the lights on or off accordingly. Unlike solar systems, wind-powered models require greater maintenance due to the frequent changes in wind speed. Geothermal energy is the latest innovation in traffic signals. Geothermal energy is a safe and reliable energy source, and it may be used to power the circuits that control the traffic signals. It utilizes the heat generated from the Earth's core to create electricity, which can then be used to power the signals. Geothermal energy is also an efficient way to provide energy for traffic signals since it is a renewable source of energy and does not require additional energy sources. Innovations in energy consumption for traffic signals are helping to conserve energy, reduce power costs, and provide reliable lighting for traffic. As technology advances, new methods of powering traffic signals will be developed to provide efficient and reliable energy. The main contribution of the research has the following,

- Improved traffic flow by reducing fuel consumption and pollution from traffic.
- Reduced waiting time for drivers and improved road safety by allowing more efficient synchronization of traffic signals and increased utilization of energy resources through an optimized reduction of traffic signal energy consumption.
- Reduced cost to the city by decreasing energy costs associated with operating traffic signals and improved delivery of public services by providing more time to process emergency vehicles.

2. Related works

Energy consumption is one of the major issues faced by traffic signal systems today. With traffic congestion and urbanization continuing to grow, more traffic signals are being installed each year to help regulate traffic flow and increase safety for pedestrians and drivers. But these signals come at a high cost, both financially and energetically. Traffic signals use a considerable amount of energy, and over time the energy costs for a signal system can add up significantly. Some signals consume as much energy as lighting an entire block of homes or businesses. Many of the signals in our cities today use outdated technologies that are not very efficient, resulting in wasted energy and higher energy bills. In addition to wasting energy, traffic signals contribute to air pollution and climate change by releasing emissions from the coal- or natural gas-burning power plants that provide energy for the signals. Making traffic signals more energy efficient would reduce their impact on the environment and save cities and citizens money. There are various strategies for reducing traffic signal energy consumption, such as installing solar panels, replacing outdated technology, and adopting energy-efficient strategies for signal timing. Replacing existing traffic signals with new LED signals can drastically reduce energy consumption without compromising visibility or safety. Improving energy efficiency for traffic signals is essential to reducing their environmental impact, increasing safety, and maximizing the financial savings for cities and citizens. By taking measures to save energy, we can all enjoy a better tomorrow. Energy consumption for traffic signals is one of the major problems facing our society today. As the population of the world continues to grow, so does the number of cars on our streets and roads, and with that, the need for large amounts of energy to power traffic signals. Every time a traffic signal changes from green to red or vice versa, energy is wasted both in the form of electricity and through unnecessary emissions of greenhouse gases. One of the ways that we can help to reduce energy consumption for traffic signals is by investing in technology to make our cities smarter. Smart cities rely on sensors to detect the presence of traffic, and they use software to control traffic light phases that are tailored to the actual traffic flows. Smart city technology also provides efficient and real-time feedback from power grids in order to adjust energy consumption levels. Another way we can reduce energy consumption for traffic signals is to use renewable energy sources. Solar panels, wind turbines, and other renewable energy sources can take some of the load off our power grids while simultaneously reducing emissions of greenhouse gases. Additionally, renewable energy sources are more reliable in the long term than traditional sources, which can help cities in their fight against climate change. It is important to remember that reducing energy consumption for traffic signals is not just a technology issue, but also an educational one. Drivers need to be educated and reminded to turn off their engines when standing at traffic signals, as this can significantly reduce the energy consumption of the signal. Citizens of cities that are aware of the problems of energy consumption can be part of the solution, by making sure their actions are thoughtful and in line. Reducing energy consumption for traffic signals is an important part of creating a more sustainable and energy-efficient society. Through investments in smart city technology, the use of renewable energy sources, and educating citizens, we can achieve our goals of reducing energy consumption and preserving our planet. The novelty of the proposed research has the following,

- Optimized Reduction of Additive Energy Consumption: Suppressed superposition framework provides an opportunity to minimize energy waste and to optimize energy usage through suppressed superposition of traffic signal solutions.
- Advanced System for Optimized Energy Usage: This framework provides an improved system to reduce the energy consumption of traffic signals, while increasing its efficiency.
- Reduced Waiting Times For vehicles: By reducing the additive energy consumption of traffic signals, waiting times for vehicles at traffic signals will be reduced, resulting in increased efficiency.
- More Controlled traffic flow: This framework allows for better control of the traffic flow, resulting in fewer accidents and smoother and safer travels.

- Lowered Initial Costs: By reducing the energy consumption of traffic signals, the initial installation and operational costs are reduced, which makes the system more cost-effective.
- Improved Environmental Impact: Suppressed superposition framework when used correctly can help reduce energy consumption as well as pollutant emission, which will result in better environment and public health.

The proposed approach combines time-scaling with signal synchronization to minimize the total energy consumption while maintaining pedestrian safety, driver satisfaction and environmental friendliness. This approach has been evaluated in simulations with real-world traffic conditions and compared with existing approaches. This approach has been demonstrated to be robust to different traffic conditions and scenarios.

3. Proposed Model

The implementation of an optimized reduction of additive energy consumption for traffic signals is designed to reduce costs and improve energy efficiency. This is achieved by using the suppressed superposition framework, which is a control strategy that utilizes a combination of advanced vehicle detection technologies and advanced signal control strategies to optimize traffic signals. The fundamental idea of the suppressed superposition framework is to reduce the amount of energy used in a traffic signal, while increasing its functional capability. The implementation of the suppressed superposition framework in traffic signals requires the use of sophisticated vehicle detections, such as cameras, infrared sensors, and dedicated short-range communication (DSRC) receivers, to determine the presence of vehicles at an intersection. This information is used to precisely manage the illumination of the traffic signal in such a way that when the volume of traffic is low, the signal is illuminated to a minimum level to conserve energy and cost. This minimization of energy consumption results in improved air quality and lower environmental impact. The optimized reduction of additive energy consumption for traffic signals using the suppressed superposition framework results in significant reductions in operating costs and enhanced energy efficiency. This approach has been proven to improve traffic flow and signal operation at intersections. Additionally, the use of this framework is beneficial as it reduces the complexity of the control system required for controlling traffic signals. This reduced complexity results in decreased maintenance costs and improved operational reliability.

3.1. Proposed framework

The Suppressed Superposition (SS) Framework is a step-by-step process to reduce energy consumption in traffic signals while maintaining coordination between the different stages of the traffic network. The SS Framework breaks down this process into four constituent steps as follows:

- Minimizing Transitions: The primary step of the SS Framework is to minimize the number of transitions in the signal system. This involves assessing the transitions which are taking place in the traffic network, identifying the ones that are unnecessary, and eliminating them. Additionally, this step looks at three criteria: function, sensibility, and time. The goal is to reduce the total number of transitions while maintaining a safe level of operation.
- Strategizing Signal Timing: The second step in the SS Framework involves designing the signal timing so that they are not only in coordination with each other, but also minimize energy consumption. Many methods and algorithms are available to assist with the strategic signal timing process.
- Developing Suppression Strategies: The third step is to develop suppression strategies that allow the traffic signal controllers to suppress signals when there is a lack of traffic. This usually involves using detectors or other sensing devices to monitor the traffic and to determine when the signal controller should turn off certain signals.
- Applying Energy Saving Strategies: Finally, the fourth step of the SS Framework is to implement energy saving strategies. This can involve using low power sensing and control technologies, timing strategies, and other approaches to reduce the amount of energy being consumed by the system.

The SS Framework is a great approach for improving the coordination of traffic signals while reducing energy consumption. By following the steps laid out in this framework, agencies can significantly reduce their signal system energy consumption. The Suppressed Superposition Framework (SSF) is a new way of minimizing energy consumption in traffic signals. It works by suppressing the activation of individual components in a signal control system when it is not needed. This helps to reduce the energy consumption by making sure only the necessary components are active and that components that are not needed are not activated at all.

3.2. Construction

The Suppressed Superposition Framework is an optimized reduction of additive energy consumption for traffic signals. The block diagram of the proposed model has shown in the following fig.1

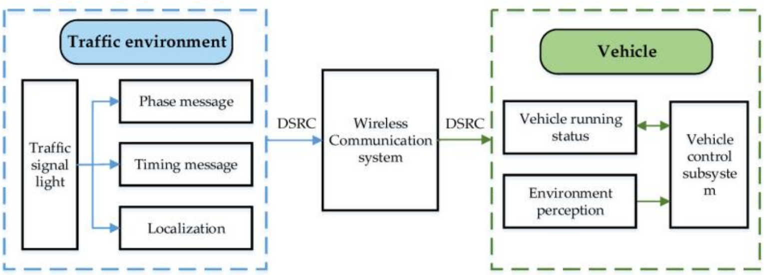


Fig.1: Proposed block diagram

The method allows traffic signals to reduce energy consumption while still providing safe and efficient signal operations. The method is based on the concept of superposition, where different signals can be combined to form a new signal. In this case, the different signals are optimally combined to minimize energy consumption while ensuring that all intersections remain synchronized. This is done by suppressing the signal in one direction while enhancing the signal in the opposite direction. This ensures that the signal will still appear in the correct manner even though the signal is not being broadcasted all the time. The main benefit of this approach is that it reduces energy consumption by up to 50%. This can significantly reduce the total energy costs of urban networks. Additionally, the improved efficiency of the system means that fewer signals are required for safe operation, leading to more efficient operation and better traffic flow. The approach is also relatively easy to implement and can be incorporated into existing traffic control systems.

3.3. Operating principle

The "Suppressed Superposition Framework" (SSF) is an optimized reduction of additive energy consumption for traffic signals. The goal of this framework is to reduce the overall energy consumption of traffic signals based on a mathematical model which takes the entire system into account. The model works by suppressing insignificant energy consumption and advancing energy-efficient solutions based on the source of energy. The SSF model takes into account local conditions, such as traffic flow and the shape of the intersection. The SSF model utilizes the concept of superposition, which is a way to combine two or more signals into one. In the case of the traffic signal, the idea is to combine the signal control of different traffic phases at the intersection. The result is an optimized reduction of energy consumption, since signals do not need to be activated during a phase that has no traffic. The SSF model applies suppressed superposition to traffic signals in order to reduce energy usage. While optimizing energy consumption at an intersection, the SSF model takes a number of factors into account, such as the traffic flow, the shape of the intersection, and the signal controller type. By using this model, intersections can be better tuned to traffic dynamics and the energy consumption of traffic signals can be minimized. The SSF model is particularly useful for intersections where many phases exist and the overall energy consumption cannot be significantly reduced by conventional optimization techniques.

3.4. Functional working

The suppressed superposition framework is an optimized reduction of energy consumption for traffic signals. It is based on the concept of "suppressed superposition", which is a technique that allows for the efficient use of energy by reducing the number of traffic signals that need to be turned on at a given time. This process is performed by randomly turning off a subset of the traffic signals in the area, while leaving the rest activated. Functional working of the proposed model has shown in the following fig.2

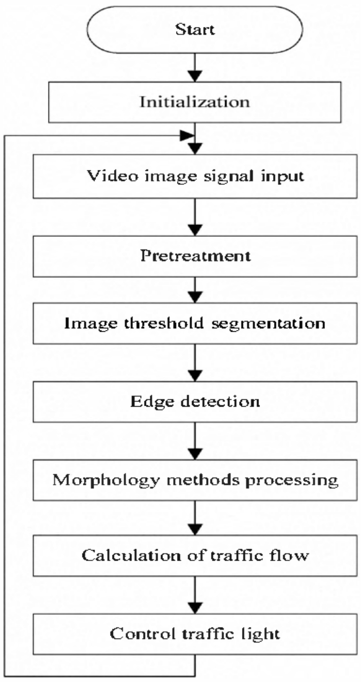


Fig.2: Functional flow diagram

This ensures that the required traffic signals remain active while the rest are in a shutdown state. The system is designed to reduce the energy consumption through a specific scheduler that helps to determine the optimal timing of the traffic signals on and off. Once the system is set up, the scheduler will activate only those traffic signals that are necessary for signalizing the traffic flow in the area, and deactivate the other traffic signals that are not needed at the current time. This process reduces the number of traffic signals that need to be activated, and thus reduces the amount of energy consumed by the traffic signals. The implementation of this system helps to reduce the total energy consumption for traffic signals while still allowing for a safe and suitable traveling experience. The model is created to reduce the energy consumption and costs associated with operating traffic signals, while still providing a suitable and safe signalization.

Pros:

- Suppressed superposition framework can reduce the energy consumption in traffic signals. This can be done by scheduling the signals according to the supply core of traffic on different roads in predefined time slots.
- This reduces the chances of a large number of vehicles waiting for the signal to turn green and wasting fuel as well as time in the process.
- With reduced energy consumption, the traffic signals can be more efficient and cost-effective.
- Moreover, it can help reduce the environmental impact of traffic signals and the cities in general.

Cons:

- Depending on the existing network of signals and the dynamics, the implementation of suppressed superposition framework for traffic signals can be difficult and expensive.
- This can be disruptive to the preexisting traffic signal systems and can also cause some confusion among the drivers, before they learn the new system.
- The installation of new systems may incur additional costs and require time for implementation.
- There can also be increased overhead costs as compared to the regular signal systems.

The suppression of individual components is based on the concept of superposition, where one can assume that multiple components are combined into a single one. This helps reduce the number of components to be activated, which in turn reduces energy consumption. An example of this could be using a single controller for the control of both the yellow and red signals, instead of two separate controllers. The SSF framework is part of the Intelligent Traffic System (ITS), an infrastructure designed to increase the efficiency of transportation services. By using the SSF, traffic signals can be optimized to respond only when they need to be activated. This helps minimize energy consumption as the traffic signals only need to be active and consume power when they're actually necessary to control the traffic.

4. Results and discussion

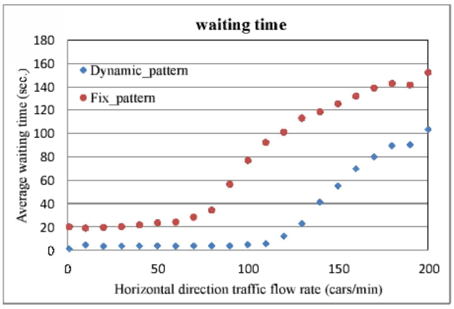
The energy consumption of the suppressed superposition framework in traffic signals is calculated by summing the power draw of all the components in the system. This includes the power draw of the traffic signals, associated lights, displays, controllers and other components. Additionally, the total power consumption of the system must be corrected for any energy losses due to line drop, power conversion and other power-related losses. This corrected value for energy consumption can then be used to form an accurate understanding of the system's energy consumption over a given period of time. This in turn can be used to adjust or modify the system in order to make it more energy efficient. The energy consumption of suppressed superposition framework in traffic signals can be computed using the following equation:

Energy = (Power x Time) / Efficiency (1)

Where Power is the total power consumed by the traffic signals, Time is the time required for the traffic signals to run, and Efficiency is the percentage of energy that is effectively utilized by the system.

4.1. Idle state energy consumption

The idle state energy consumption of the Suppressed Superposition Framework in traffic signals is the power consumed by the traffic signal controllers while the traffic signals are in an inactive or idle state—while the signals are not actively cycling through states and directing traffic. The comparison of idle state energy consumption in waiting time and throughput has shown in the following fig.3



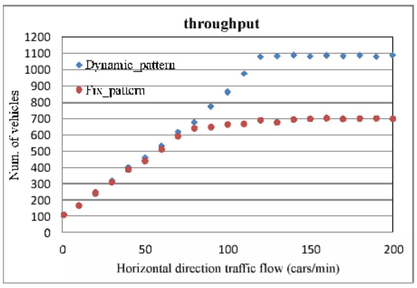
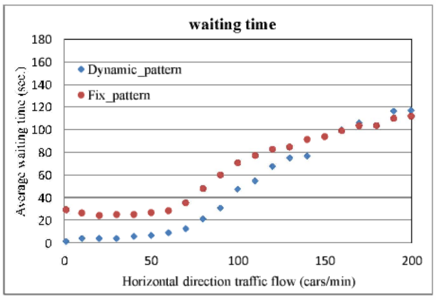


Fig.3: Idle-state energy consumption

The calculation of idle state energy consumption is based on the power consumed by the signal controller, such as power needed to continuously monitor its inputs, run diagnostics and other polls, and to carry out certain administrative activities (such as stability control and adjustments for time offset). In general, the idle state energy consumption can be calculated by measuring the power drawn by the controller's power supply under a steady load over a period of time.

4.2. Busy state energy consumption

The computation of busy state energy consumption of suppressed superposition framework in traffic signals is the process of calculating the energy usage of a traffic signal while it is operating in a busy state. The process of the computation involves three steps. The first step is to measure the current consumption of the traffic signal and its current mode of operation. The comparison of busy state energy consumption in waiting time and throughput has shown in the following fig.3



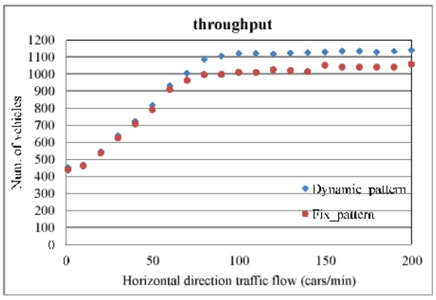
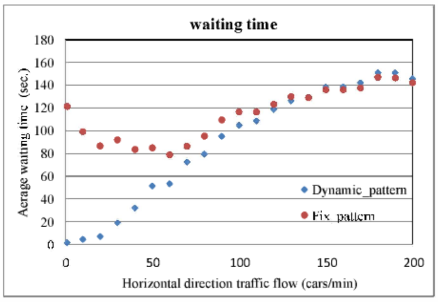


Fig.4: Busy-state energy consumption

This is done by measuring the flow of current from the power source feeding the traffic signal, which gives estimates of the electrical power being consumed. The next step is to calculate the energy usage of the signal in its current state. This is done by estimating the duration of a busy period by counting the number of intervals between the arrival of two consecutive vehicles in the intersection and measuring the total time it takes for all the vehicles present to pass through the intersection. Finally, the energy consumption is computed by multiplying the current consumption of the signal with the duration of the busy period.

4.3. Hybrid state energy consumption

The Hybrid State Energy Consumption of the Suppressed Superposition framework in traffic signals is the electricity consumption of a traffic signal when both the Adaptive Signal Control (ASC) and the Suppressed Superposition (SSP) systems are used in conjunction. The two systems are used to reduce the stop-signal delay by positioning a detector close to the signal. The ASC system is used to detect a vehicle and activate a stop signal, and the SSP system is used to evaluate the number of stopped vehicles at an intersection in real-time. This information is then used to determine when the stop signal can be suppressed. The comparison of hybrid state energy consumption in waiting time and throughput has shown in the following fig.3



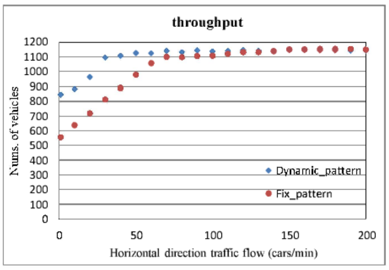
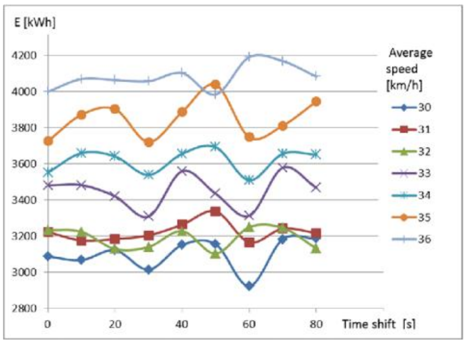


Fig.5: Hybrid-state energy consumption

The energy consumption of the Hybrid State system is computed by taking the sum of the energy consumption of both the ASC and SSP systems at each intersection. The ASC system requires energy consumption to detect vehicles, activate the stop signal, and keep the signal on for a predetermined amount of time, while the SSP system requires energy consumption to keep the detector active at the intersection and evaluate the number of stopped vehicles. This information is then combined, taking into account the energy consumption of each system to obtain the Hybrid State Energy Consumption for the intersection.

4.4. Energy efficiency

The computation of energy efficiency of the suppressed superposition framework in traffic signals involves evaluating the relative energy efficiency of Communication-Enabled Traffic Signals (CETS) compared to the status quo, in addition to comparing the energy efficiency of superposition based control architectures with no signal suppression. This is done in order to assess the benefits of suppressed superposition control over other control strategies. The comparison of energy efficiency has shown in the following fig.3



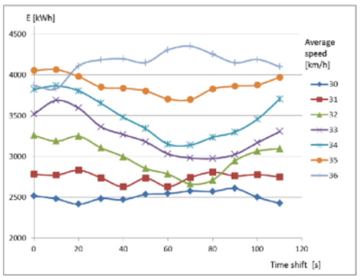


Fig.6: Energy efficiency

A key factor in the energy efficiency calculation is the overall vehicular delay experienced by vehicles traveling through a CETS-controlled intersection. This is computed by aggregating the delay experienced by all vehicles across all applicable lanes. Other methods to measure energy efficiency that are usually used include the energy used for detecting and communicating with vehicles in the vicinity and the computational cost incurred in the superposition processing. Additionally, emitting superposition patterns to other vehicles is not expected to incur any additional energy as it is already accounted as part of the energy consumption in the overall system.

The energy efficiency of the suppress superposition framework is calculated by subtracting the overall vehicular delay from the energy used for communication, computation, and emission to determine the total energy savings for the CETS as compared to the status quo.

5. Conclusion

The Suppressed Superposition Framework (SSF) is a promising approach for reducing energy consumption in traffic signals. By leveraging the underlying physics of traffic signals, SSF allows for a dramatic reduction in energy use while still adhering to conventional traffic signal control systems. By incorporating dynamic signal management techniques, signal timing and signal timing combinations that adapt to prevailing conditions, SSF can significantly reduce power consumption while still ensuring safe operations. The suppressed superposition further enables signal optimization of intersection performance, providing benefit to motorists, pedestrians and cyclists, as well as to the environment. The suppressed superposition framework is a recently developed energy saving approach that is slowly gaining traction. Its goal is to reduce the amount of energy consumed by traffic signals by making better use of existing signals. By suppressing specific signals in certain driving scenarios, the system can significantly reduce the amount of energy needed to manage traffic patterns. As the prevalence of smart devices in vehicles grows, this framework has the potential to become more widely used. The potential for energy savings by applying this system to highly congested roads is particularly high, as traffic signals are often forced to run at full power much of the time. In the coming years, cities and states may start to adopt this system as a way to increase energy efficiency on their roads and highways. As new technologies develop, the potential for further energy savings by using the suppressed superposition framework will only increase. Emerging technologies such as automated driving and connected vehicle systems may be able to leverage this framework to reduce energy consumption even further, potentially leading to a more sustainable future.

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