A Wireless Mobile-Phone Approach to Traffic Signal Preemption for Faster Service of Emergency Vehicles

Hussein R. Al-Zoubi, Sahar Z. Shatnawi, Alaa I. Kalaf , Balqees A. Mohammad
Department of Computer Engineering,
Hijjawi Faculty for Engineering Technology,
Yarmouk University, Irbid 21163, Jordan.

ABSTRACT
Modern cities contain extensive numbers of road intersections. The coordination of traffic at these intersections is usually governed by traffic signals. During rush hours, waiting at traffic signals consumes substantial amounts of time even if for short distances. Since the operation of emergency vehicles mandates reaching the accident location and then the hospital at the minimum time possible, traffic signal preemption by emergency vehicles represents a valuable solution, where the emergency vehicle possesses the capability of evacuating the traffic ahead of it at the traffic signal and owns the right to cross the road. After the passage of the emergency vehicle, the traffic signal returns to its normal operation. Several approaches have been proposed in the literature for preempting traffic signals by emergency vehicles. However, the current solutions suffer from certain drawbacks. In this paper we propose a novel approach for traffic signal preemption using wireless mobile-phone transmission. Compared to the state-of-the-art solutions, the proposed system is a low cost and can be made of off-the-shelf components. Simulation results show the effectiveness of the proposed approach.

General Terms
Wireless Transmission, Cellular Transmission, Road Traffic.

Keywords
Traffic Signal Preemption, Emergency Vehicle, Siren, Hardware Design.

1. INTRODUCTION
Humans represent the most valuable asset for any nation. Saving lives and keeping people in best health thus, is a fundamental obligation. However, accidents happen to people at work, home, street, or even in vacations. Accidents like burning, electrical shocks, drowning, falling from a high place, poisoning, etc. happen every day. Accidents result in injuries or sometimes deaths. However, if squad teams reach the accident quickly, they can play a great role in saving lives and rescuing people. To achieve this goal, hospitals, fire stations, and police and civil defense centers spread evenly in modern civilizations among city areas, towns, villages, and in rural areas. The rapid growth in populated areas however, places burdens on the fire/rescue and other emergency vehicles [1].

Several techniques have been implemented to help emergency staff reach the accident location, and then the hospital faster. The most common form is the use of siren which an ambulance uses for the purpose of making a distinguishable noise. As soon as a driver hears this special noise she tries to stop or make way for the emergency vehicle. However, this common method has some disadvantages like sound pollution [2]. It can also cause disturbances to traffic and may pose threats of collision or traffic congestion. On the other end, emergency aircrafts have been used, but this solution is very costly and inapplicable in many situations. Prehospital management that allows telediagnosis, long distance support, and teleconsultation has also been made possible by using mobile healthcare [3], [4-6]. Although this approach seems promising, it is still under development with very expensive equipment. Nevertheless, our proposed approach does not contradict with the last mentioned approach and the two approaches can be incorporated into modern ambulances [7].

Traffic signal preemption for emergency vehicles helps in reducing delay time, improving safety and minimizing the cost [1]. Using signal preemption to provide emergency vehicles a green light at intersections can reduce conflicts, improve emergency response times, and reduce other drivers confusion and thus can dramatically reduce the number of emergency vehicle crashes. This has the potential to translate into cost savings for the community. Emergency vehicle traffic signal preemption systems are a promising approach which comes with many benefits for individuals and the community. There has been extensive research on this subject from different perspectives. The subject of automatic traffic light control systems has also gained special importance in the recent years [8-12].

In this paper, we propose using wireless cellular phone transmissions to perform the operation of preempting traffic lights by emergency vehicles. The emergency vehicle driver uses a cellular telephone to call another cellular telephone embedded within the traffic light controller, which triggers the preemption signal that switches the state of the traffic light to the emergency preemption state. At this point, the green light is granted to the direction from which the emergency vehicle is approaching. The traffic light switches back to its normal state after a specified amount of time that enables the emergency vehicle to pass the intersection safely. To the best of our knowledge, we think that this idea is novel.

This paper is organized as follows: in Section 2, we talk about the state-of-the art related work for traffic signal preemption by emergency vehicles. In Section 3, we present our proposed preemption system. The hardware design and full details of the proposed system are provided in Section 4. Next in Section 5, Simulation Results are given and discussion can be found in Section 6. Finally, in Section 7 we conclude our paper and talk about future work.

2. RELATED WORK

The two salient approaches for wireless traffic signal preemption use sound recognition and infra red [13]. Preemption using sound recognition utilizes the siren of the emergency vehicle and employs sound recognition. Several drawbacks for this sound recognition approach can be clearly seen. First, it is difficult to know the direction from which the emergency vehicle is approaching. So, it is very likely that wrong signals or directions are preempted. Second, because of noise pollution, other sounds around may interfere with the emergency vehicle siren sound. Third, using the emergency vehicle siren itself too frequently adds to the noise pollution. Fourth, complex software is needed to accurately recognize the siren sound. However, sound recognition systems are error prone as known, and never achieve 100% accuracy. Moreover, different siren manufacturers in general sell sirens with different sounds, which makes the recognition mission more difficult.

The infrared approach enables emergency vehicles to preempt traffic signals using certain infrared transmission frequencies. This approach suffers from several shortcomings. First, the infrared transmitter should be fixed on top of the emergency vehicle on a place that can be clearly seen from a distant place (Figure 1 [1]). The infrared receiver on the other side should be mounted on a high place at the traffic light (Figure 2 [1]). The infrared transmitter and receiver should be within an effective line of sight from each other in order to operate properly. Second, infrared transmission is greatly affected by weather conditions, and even is affected by sunlight. Third, infrared signals are highly attenuated with distance and cannot travel more than few tens of meters. Fourth, signals transmitted using the infrared technology cannot penetrate obstacles. In light of this, the emergency vehicle might not be able to preempt the traffic signal if it is hidden by a building or a tree, or being behind a hill or a curve. In addition, the emergency vehicle must be close enough to preempt the traffic signal. This may incur delay since longer times are needed to evacuate vehicles ahead of the emergency vehicle. A short distance separating the emergency vehicle and traffic signal makes the emergency vehicle slows down and even decelerates to zero. Moreover, similar to the siren approach, it is very likely that wrong signals or directions are preempted using infrared. Finally, the infrared solution may not provide the required security in such a sensitive application as any infrared transmitter may preempt the traffic signal if the transmission frequency is compromised and changing the frequency may be a costly process.

Fig 1: Infrared-based preemption systems, the infrared transmitter should be fixed on top of the emergency vehicle on a place that can be clearly seen from a distant place [1].

3. THE PROPOSED TRAFFIC SIGNAL PREEMPTION SYSTEM

The proposed system consists mainly of a sender mobile phone, a receiver mobile phone, a headset, and a dual-tone multiple frequency (DTMF) chip. The sender is a regular mobile telephone used by the emergency vehicle driver. The receiver is another regular mobile telephone embedded within the traffic light controller. The receiver telephone is switched to the automatic answering mode. This service exists in almost all mobile phone devices.

Fig 2: Infrared-based preemption systems, the infrared receiver should be mounted on a high place at the traffic light. The infrared transmitter and receiver should be within an effective line of sight from each other in order to operate properly [1].

When the emergency vehicle driver dials the phone number of the intended traffic light, that phone automatically answers and the connection between the two mobile phones is established. At this point, the emergency vehicle driver sends a security code. It is known that for each button on the telephone keypad, two frequencies are generated. When the receiver telephone receives the security code, the headset takes the tones and outputs them to the DTMF, which uses digital counting techniques to detect and decode tone pairs. For each digit of the security code, the DTMF generates an impulse signal with four-bit binary code.

The binary numbers generated by the DTMF are fed to the preemption system explained in Section 4, which verifies the correctness of the received code. The system then requests the traffic light controller to switch to the preemption mode if the received security code is correct. Otherwise, the preemption system does nothing. The preemption state lasts for a reasonable amount of time that gives a safe passage to the emergency vehicle after which the traffic light controller toggles back to its normal operation.

Our preemption system can also handle rare situations when two emergency vehicles arrive at the same intersection at the same time from two different directions. In these cases, the green light is granted to the emergency vehicle that dials first, the other one has to wait. The process followed in the proposed system is illustrated by the flow chart shown in Figure 3.

Our proposed system is very convenient for use by the emergency vehicle driver, who just needs to call the correct number. As an example, Figure 4 shows how the numbers can be saved on the driver's mobile phone. Traffic lights are identified by the names of the intersecting city streets. This example illustrates saving the traffic light phone numbers in the contacts' list of the mobile phone. Figure 4 shows a sample of saved intersections: the intersection of Athens Avenue and Green Road, the intersection of Cold Water Road and Mary Street, the intersection of Jackson Drive and Hillside Avenue, and the intersection of Jeff Street and University Drive. Making the phone call and sending the PIN code do not interrupt the emergency vehicle driver since in most of the cases; he or she has a companion, to whom this job can be handed.

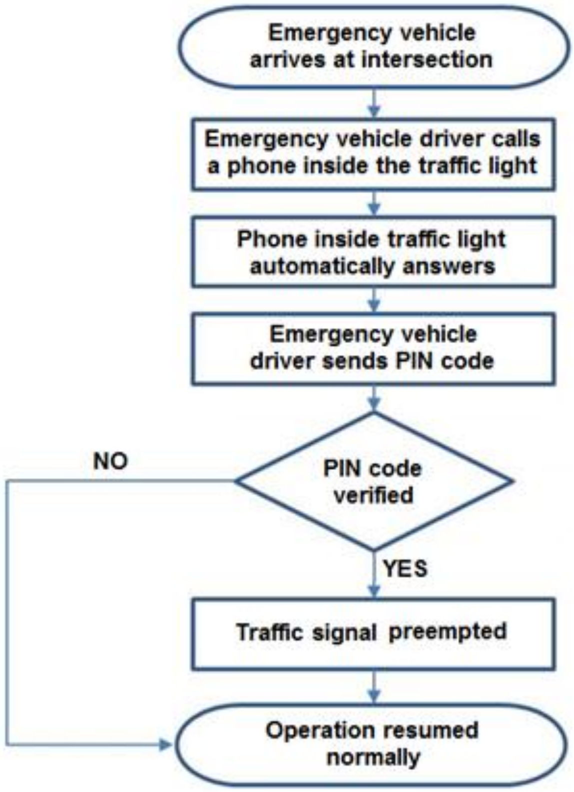

Fig 3: A flow charts illustrating the process followed by the proposed system to preempt a traffic signal by an emergency vehicle. When the emergency vehicle comes close to the intersection and depending on the volume of congestion at the traffic light, the emergency vehicle driver chooses the proper time to make a telephone call to the mobile phone specific to this intersection. This allows traffic ahead of the emergency vehicle to evacuate and prevents the emergency vehicle from a possible slow down. After the phone inside the traffic light automatically answers, the emergency vehicle driver sends the PIN code, which is unique to the direction from which the emergency is coming. The proposed system verifies the PIN code and preempts the desired traffic signal. After preemption, the traffic light resumes normally. If the transmitted PIN code is incorrect, the traffic light continues its operation normally.

4. THE HARDWARE DESIGN

The proposed traffic light preemption system has been built using the minimal number of components. Our proposed system is shown in Figure 5. The left side of the circuit represents the sequential logic, while the right side is the combinational part. The DTMF has two output signals: the DTMF pulse and the 4-bit hexadecimal code. The DTMF pulse is a short-period pulse signal that goes from high to low and then back to high whenever the Receiver mobile receives a single digit number (that the Sender mobile sends), and which the headset outputs to the DTMF. The DTMF pulse acts as a clock for a 2-bit counter and a 4 × 16-bit buffer. The other DTMF output signal is the security code, which represents a digit of the PIN code to be used to preempt the traffic signal in a certain direction. Depending on the speed at which the user strokes keys, each digit of the PIN code (in our experiments, we have decided to use a 4-digit PIN code) is transmitted from the sender mobile to the receiver mobile, and then to the DTMF, serially. Each digit of the PIN code is a 4-bit hexadecimal number. In our design, we have used a 4 × 16-bit buffer, a 4-location small storage device to save the PIN code. This buffer has a 4-bit D_{in} (input data line) connected to the output of the DTMF. To make writing data on the buffer possible at any time, the write enable (WREN) of the buffer has been hardwired to high voltage. Writing on the buffer is performed at the falling edge of the clock. The 2-bit output lines of the counter act as address lines for the buffer (A0 and A1). Therefore, the first digit of the PIN code is stored at the first 4-bit location of the buffer, the second digit at the second 4-bit location, etc. The same clock is used for both the 2-bit counter and a 4 × 16-bit buffer so that both are updated simultaneously at the falling edge of the clock. Reading data from the four data locations of buffer is done in parallel using a 16-bit D_{out} (output data line). Reading data from the buffer is also possible at any time by having the read control signal (Rd) of the buffer hardwired to high voltage.

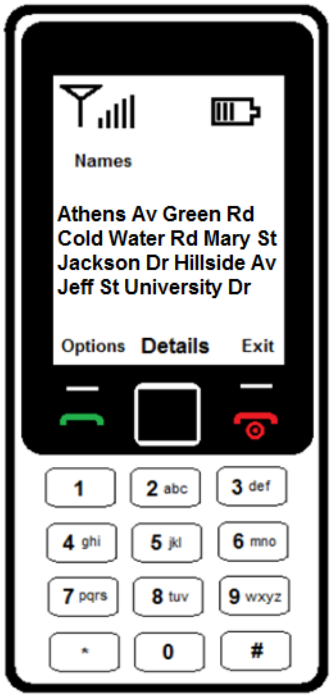

Fig 4: Saving traffic light numbers in the driver's mobile phone. For ease of use, intersection phone number is saved at the phone's contacts list using the names of the streets that intersect. This figure shows a snap shot of contacts list of the emergency vehicle driver's mobile. Here, four intersections appear: the intersection of Athens Avenue with Green Road, the intersection of Cold Water Road and Mary Street, the intersection of Jackson Drive and Hillside Avenue, and the intersection of Jeff Street and University Drive.

Our proposed approach depends on using a unique phone number for each intersection, with a traffic signal, in the city. Thus, the emergency vehicle has to preempt each signal on the route independently. Nevertheless, each direction at the same intersection is preempted using a different PIN code. This reduces the implementation and maintenance costs, where the alternative would be to use a unique phone number for each direction.

The combinational part of the circuit consists of comparators, OR gates and an encoder. It is customary to use XOR gates when making comparisons. The symbol of a basic 2-input

XOR gate and the equivalent truth table of the XOR logical operation (usually denoted by the symbol ⊕) are shown in Figure 6. The output of (b0 ⊕ b1) is 1 only when b0 and b1 are different. In our design, we have used comparison logic for each direction. Each comparison logic consists of 16 2-bit input XOR gates. The first input of the XOR_i gate is the i^{th} bit of the 16-bit PIN code used for direction d (Pd_i). The other input is the i^{th} bit of the 16-bit PIN code that the emergency vehicle transmits and is stored on the buffer (D_{outi}). The output of the comparison logic is a 16-bit line that should be all zeros only when the transmitted PIN code is correct. This is the input of a 16-bit OR gate that generates a one-bit output of zero if and only if all the 16-bit inputs are zeros.

To know which direction the emergency vehicle is trying to preempt, we have used a 4 × 2 priority encoder with four active-low inputs. The active-low chip enable of the priority encoder has been hardwired to the ground to function all the times. The value of the two output lines indicates which of the four inputs has been asserted. Moreover, the priority encoder has an additional output line, the INT signal, which is asserted only if the encoder's inputs are asserted. i.e., the value of INT is 0 if no inputs are asserted. The purpose of using a priority encoder is to make sure that only one direction can be preempted at any time. However, the order of priority among the directions is usually unimportant. The two outputs of the priority encoder plus the INT signal are fed as inputs to the traffic signal encoder to preempt the desired direction. The INT signal has another job; it has been connected to the CLR input of the buffer to erase its contents and prepare it to accept the forthcoming PIN code after every successful preemption.

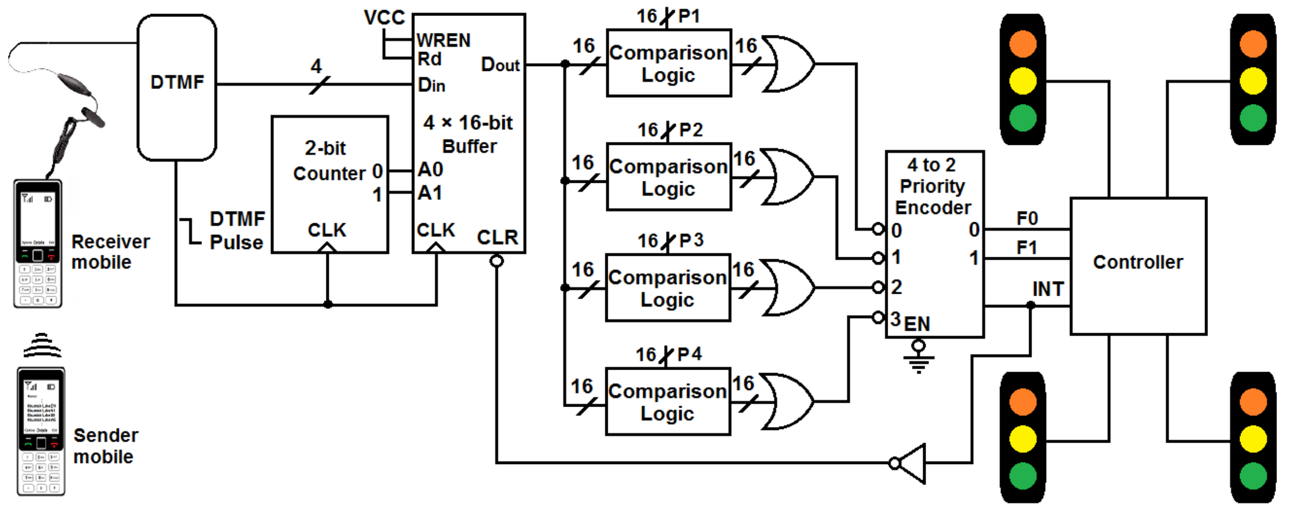

Fig 5: The proposed traffic signal preemption system. The data flow is left-to-right. The sender mobile is with the emergency vehicle, while the receiver mobile is fixed in a secure place at the traffic signal. The left side of the circuit represents the sequential logic, while the right side is the combinational part. The output of the preemption circuit is fed into the traffic signal controller to control its operation during an emergency. Normal operation is resumed after that.

(a)

b0	b1	C
0	0	0
0	1	1
1	0	1
1	1	0

(b)

Fig 6: The Exclusive OR (XOR). (a) Symbol of a basic 2-input XOR gate. (b) The equivalent truth table of the XOR logical operation (usually denoted by the symbol ⊕), the output is 1 only when the inputs are different.

5. SIMULATION RESULTS

The proposed preemption system has been implemented in hardware on Altera-CycloneII FPGA. Simulation results have been carried out using Quartus II version 7.0. Our focus in the simulations was to verify the correct functionality of the proposed approach. Therefore, we have considered two cases; when the receiver phone receives a valid and an invalid PIN codes. We need to note here that whenever the receiver phone rings, it is highly probable that the call comes from an authorized caller. Nevertheless, an additional security procedure is reinforced using PIN codes. Simulations have been carried out for an intersection with four signals as shown in Figure 7. PIN codes 1234, 5678, 9876, and 2345 were arbitrarily chosen for traffic signals 1, 2, 3, and 4, respectively. The design of Figure 5 has been used in the simulation. Therefore, the following signals appear in the simulation results: D_{in}, DTMF Pulse, D_{out}, A0, A1, F0, F1, INT, P1, P2, P3, and P4.

Figure 8 shows the simulation results obtained when the received PIN code is correct. In this case, the numbers 5, 6, 7, and 8 have been consecutively received by the receiver phone at different instances of time. This is indicated by signal D_{in}, that feeds data from the DTMF to the buffer. The DTMF Pulse goes from high to low at time intervals shortly after the receipt of each of the PIN digits. The counter is incremented at each DTMF Pulse. A0 and A1 values illustrate this. Therefore, D_{out} has concatenated values of 5, 6, 7, and 8 and shown in Figure 8 as D_{out1}, D_{out2}, D_{out3}, and D_{out4}, respectively. As we see, the value stored at the buffer matches one of the four PIN codes. Specifically, it matches the PIN code for traffic signal 2. Consequently, the second comparison logic generates all zeros signals, followed by a low output generated by the second OR gate, which triggers the encoder to produce an INT pulse at around 200 ns. In addition, F0 took the value 1 and F1 the value 0. The INT pulse and values of F0 and F1 instruct the traffic light controller to grant the GREEN light to signal 2, while signals 1, 3, and 4 switch to RED. INT also clears the contents of the buffer.

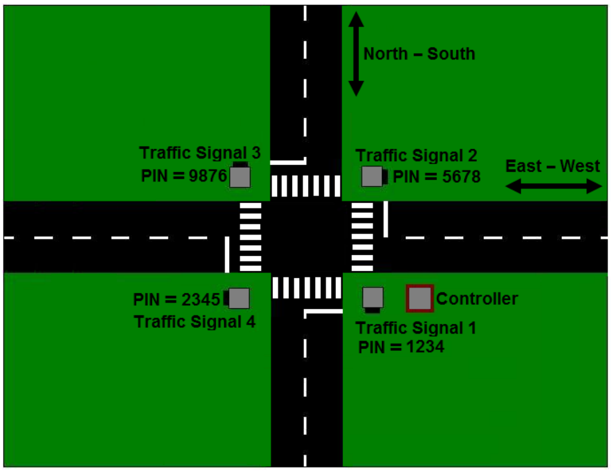

Fig 7: An intersection with four traffic signals. The operation of the traffic signals is controlled by the traffic light controller. Traffic signal 1 directs traffic coming from the south. For preemption, traffic signal 1 is assigned PIN code 1234. Traffic signal 2 directs traffic coming from the east and is assigned PIN code 5678. Traffic signal 3 directs traffic coming from the north and is assigned PIN code 9876, and traffic signal 4 directs traffic coming from the west and is assigned PIN code 2345.

The case of an invalid PIN code is shown in Figure 9, where the numbers 3, 4, 7, and 8 have been consecutively received by the receiver phone and saved on the buffer. This example shows that the value stored at the buffer does not match any of the four PIN codes. Therefore, none of the four OR gates generates a low output, and hence INT stays at a low voltage. The traffic light controller continues to operate normally (no preemption) since no INT pulse is received by the controller.

6. DISCUSSION

The proposed approach possesses many attractive features. Among others, we here talk about the most prominent points. Simplicity and ease of installation, as has been shown in the previous section, our proposed design consists completely of low cost off-the-shelf components. The connections are straightforward and do not require professional skills, to compare with one of the most popular products in the market, the OpticomTM Infra red traffic light preemption system of the Global Traffic Technologies, LLC (GTT) [14]. The OpticomTM infra red system consists of many components, mainly the OpticomTM 792 Emitter and the OpticomTM 721 Detector. The Emitter must be mounted on top of the emergency vehicle with the required housing. The detector must be fixed on top of the traffic light on a place that can be clearly seen by the emergency vehicle. Installation and maintenance requires closing the street and using a winch. On the other hand, our proposed design can be simply hidden inside the traffic light controller as it occupies a small area, with very short cables. It can be easily replaced and maintained.

The proposed system does not require line of sight and not affected by weather. Unlike the state-of-the-art designs, our proposed approach does not require line of sight to operate. This feature allows the emergency vehicle to preempt any traffic light even if it is hidden by a building, a tree, etc., or being behind a curve. Moreover, the proposed design is to a great extent not affected by weather conditions. The OpticomTM system on the other hand is based on the infrared technology that requires line of sight. Cost effectiveness, as mentioned in the previous section, our proposed design consists of low-cost off-the-shelf components. The OpticomTM system on the other hand is at least two to three orders of magnitude more expensive. Convenience, our proposed system is very convenient for use by the emergency vehicle driver, who just needs to call the correct number. As an example, Figure 4 shows how the numbers can be saved on the driver's mobile phone. This does not interrupt the emergency vehicle driver since in most of the cases; he or she has a companion, to whom this job can be handed. Security, as mentioned in the previous section, it is not enough to know the mobile numbers of the traffic light in order to preempt it; a security code is also required. The numbers as well as the security codes are both unknown to the public. This makes our proposed design more secure than the existing ones.

Using unique phone number for each intersection and a different PIN code for each direction removes the possibilities of preempting more than one signal at the same time or preempting the wrong signal or wrong direction, especially in the case of traffic signals being close to one another. This adds accuracy to the benefits of our proposed system. PIN codes are left as inputs and can easily be modified at any time when desired. In the 4-direction intersection example illustrated in Figure 7, the four PIN codes are shown as 16-bit P1, P2, P3, and P4. This way, the proposed design is made flexible. Most of the contemporary traffic signal controllers allow preemption, and come with special preemption input lines. We will not delve into the details of the traffic signal controller or provide the design details of our own traffic signal controller since our objective is to provide a portable preemption system that can be incorporated with traffic signal controllers from different vendors. Moreover, if two or more emergency vehicles arrive at the same intersection and try to preempt the signal, only one of them (the one that makes the call earlier) can do so. The others will find the line busy and have to wait until the preempting emergency vehicle passes the intersection. Thus, one and only one direction of the traffic signal is preempted at any time. This excludes the possibility of making crashes and adds safety to the benefits of our proposed system.

7. CONCLUSIONS AND FUTURE WORK

Human safety lies at the top of priorities that countries commit to their people. Therefore, rescue teams do their best to save human lives and keep people proprietary. Congestion along emergency vehicles' paths however, plays a significant role in delaying the reach of emergency vehicles to the accident scene and then to the hospital. Waiting of emergency vehicles at traffic signals constitutes the greatest share of this delay. In this paper we propose a new approach for traffic light preemption using cellular phone transmissions to remotely control the operation of traffic lights by the emergency vehicle driver. Each intersection with a traffic light has a unique mobile phone number in addition to a security code. Traffic lights are preempted by emergency vehicles upon a phone call followed by PIN code verification.

The proposed system has many attractive features like simplicity and ease of installation. The proposed system does not require line of sight and not affected by weather. Moreover, our system is cost effective, convenient, secure, portable, accurate, safe, and flexible. We believe that these features qualify the proposed approach to compete and replace the existing alternatives. For future work, we suggest fully automating the system by using GPS. By knowing the location and direction of the emergency vehicle, a computer program can call the correct cell phone number at each signalized intersection en route at the proper time. We are currently working on adding this feature to our proposed traffic light preemption system.

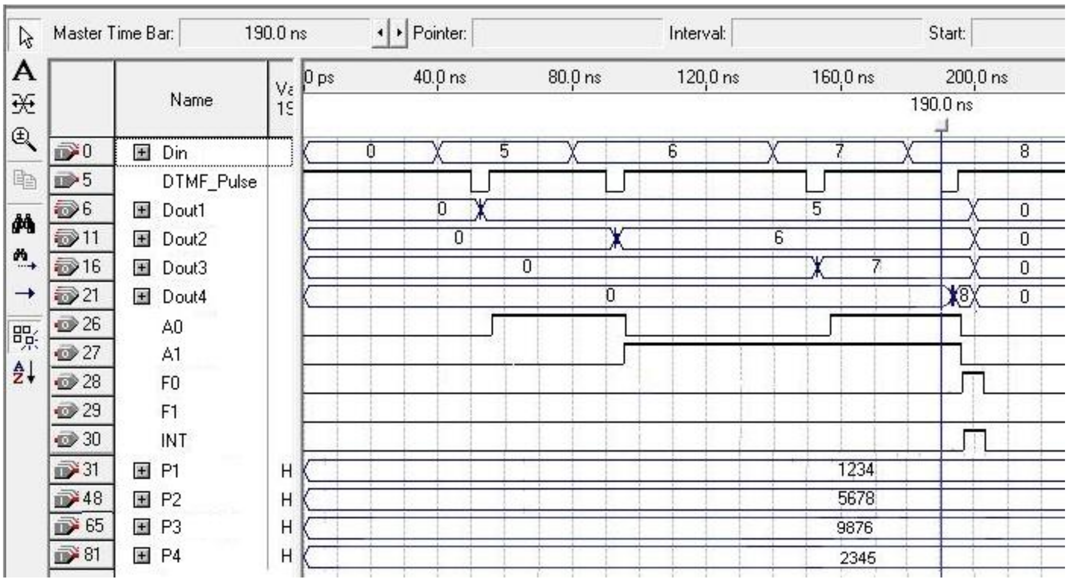

Fig 8: Simulation results obtained when the PIN code communicated between the emergency vehicle's mobile and the traffic light mobile is correct. The transmitted PIN code is 5678, which is saved at the buffer and matches the PIN code of the second traffic signal and therefore is preempted.

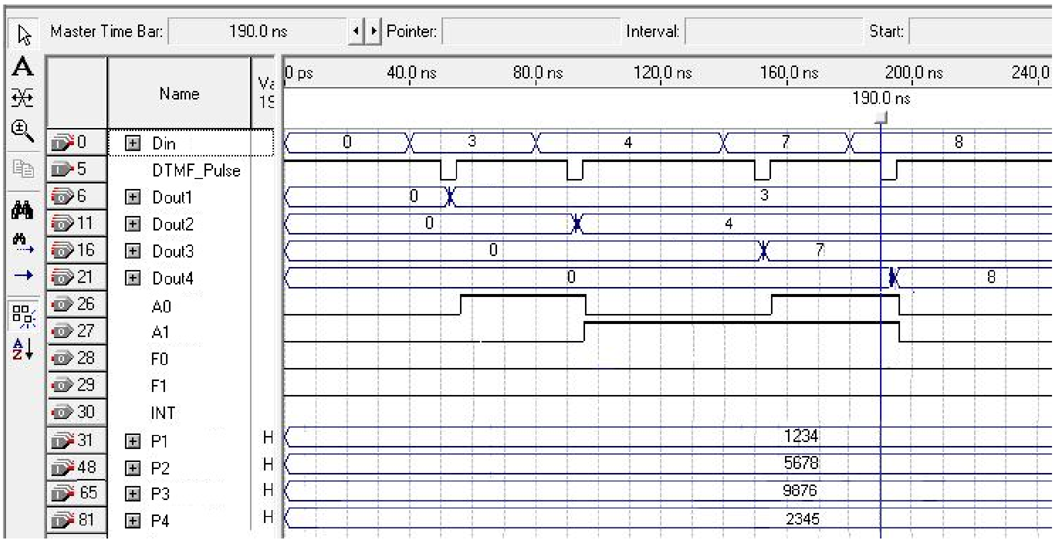

Fig 9: Simulation results obtained when the PIN code communicated between the emergency vehicle's mobile and the traffic light mobile is incorrect. The transmitted PIN code is 3478, which is saved at the buffer and does not match any of the PIN codes of the four traffic signals and the traffic light continues its operation normally.

8. ACKNOWLEDGMENTS

We would like to acknowledge the Scientific Research Fund of the Ministry of Higher Education and Scientific Research of Jordan for funding this project under contract number TH/2/14/2008.

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