DESIGN AND IMPLEMENTATION OF AN EFFICIENT WIRELESS SENSOR NETWORK BASED TRAFFIC MONITORING SYSTEM

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Abstract

Traffic congestion has been a major problem on roads around the world. In addition, there is increase in volume of traffic vehicle density at a steady rate. Thus traffic on major roads has to be controlled to keep the traffic flowing at an acceptable rate. Several schemes for replacing the predominantly used Round Robin (RR) scheme for reducing congestion at traffic junctions have been proposed. Dynamic traffic control schemes adapt to the changing traffic by monitoring the state (such as the number queued up on each lane.). These need appropriate sensing and monitoring systems.

In this paper a traffic monitoring and control system based on AMR (Anistropic Magneto Resistive) vehicle sensors, wireless sensor network and a proiritised Weighted Round Robin (WRR) scheduling technique, is developed.AMR sensors installed in road pavement detect the number of vehicles waiting in a traffic lane. The AMR sensors are connected to the master controller to form a ZigBee based sensor network. The master node consists of an ARM processor integrated with a ZigBee masternode. The traffic control algorithm is implemented at master node which is responsible for taking traffic signaling decision. It receives sensor data from all the lanes. A two level priority algorithm with weighted round robin scheduling, where first and second maximum weighted lane are to pass the signal is developed, To avoid starving the least loaded lanes, a cycle of normal round robin scheduling is performed after four rounds of proiritised weighted round robin schedule.

The proposed algorithm is simulated and compared with the standard round robin algorithm. The developed algorithm decreases the average waiting time for a commuter while maintaining the average throughput up to average loads. The development traffic monitoring system is successfully demonstrated for a four lane junction.

Keywords: Traffic Monitoring Systems, ZigBee Communication, Wireless Sensor Network, Anisotropic Magnetic Sensor, Traffic Control, Weighted Round Robin, Waiting Time, Throughput

Nomenclature

Cycle	Cycle, s
Data	bit, b
Date rate	bits per second, bps
Kbits	Kilo bits, Kb=2^{20} =1024b
Mbits	Mega bits, Mb= 2^{20} = 1,048,576b
f	Frequency, Hz

Abbreviations

ARM	Advanced RISC Machine
BER	Bit Error Rate
CC	Code Coverage
ES	East Sensor
FW	First Max Weight
GPIO	General Purpose Input Output
IC	Instruction Count
IPS	Instructions Per Second
MIPS	Million Instructions Per Second
NS	North Sensor
OS	Operating System
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
RR	Round Robin
SNR	Signal to Noise Ratio
SS	South Sensor
SW	Second Max Weight
TL	Traffic Light
TL-E	Traffic Light East
TL-N	Traffic Light North
TL-S	Traffic Light South
TL-W	Traffic Light West
UART	Universal Asynchronous Receiver and Transmitter
VIP	Very Important Person
WRR	Weighted Round Robin
WS	West Sensor
WSN	Wireless Sensor Network
ZP	Zero Padding

1. INTRODUCTION

The gathering of traffic information is a base for all kinds of traffic modelling, simulation and prediction for tasks like emission reduction, efficient use of infrastructure or extension planning of the road network as well as the intervention and resource planning. Auto accidents injure at least 10 million people each year, and two or three million of them seriously. The hospital bill, damaged property, and other costs are expected to add up to 1%-3% of the world's gross domestic product. With the aim of reducing injury and accident severity, pre-crash sensing is becoming an area of active research among automotive manufacturers, suppliers and universities. Vehicle accident statistics disclose that the main threats a driver is facing are from other vehicles. For pre-crash sensing, robust and reliable vehicle detection is the first step. A successful vehicle detection algorithm will pave the way for vehicle recognition, vehicle tracking, and collision avoidance. Current highway monitoring applications require the installation of bulky magnetic loop detectors or single mount high resolution video cameras in order to detect passing vehicles. These devices are both cumbersome and expensive to install and maintain. It is proposed that sensor networks be used as a replacement for these current technologies, since these are much simpler to install and may be less costly to maintain in the long run. The traffic parameters on the different sections of the road are not uniform, because the propagation of traffic flow is vulnerable to the influence of drivers' personality and skill, pedestrians crossing the roads, intersections of minor roads, accidents and so on. The precision and robustness of traditional traffic forecasting methods cannot meet the requirements of developing traffic control and guidance technologies.

Currently, road-traffic monitoring relies on the technology of sensors based on radar, microwaves, tubes or loop detectors as shown in Figure 1.

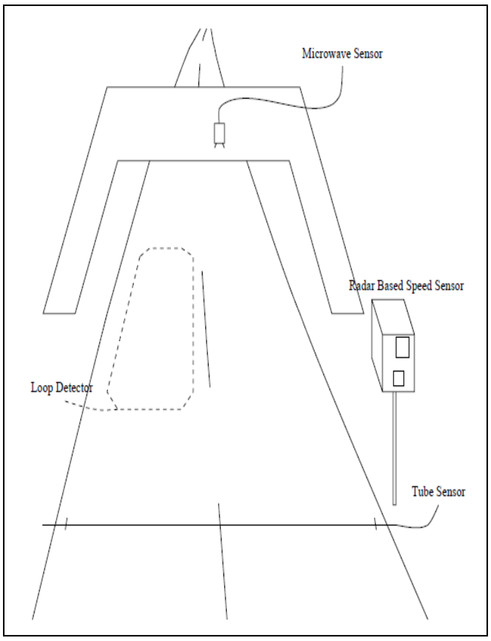

Fig. 1 Sensors Used for Road-Traffic Monitoring [1]

Radar: For accurately measuring vehicle speed

Microwave Detectors: These are usually mounted on a bridge or gantry such that they point vertically down over a lane of traffic. The device emits microwaves which are reflected on the road surface and bounced back towards the sensor. A vehicle passing under the sensor will cause interference to the reflected microwaves which enables the vehicle to be detected.

Tubes: A rubber tube fixed to the road surface across the width of a lane of traffic forms the basis of this sensor. One end of the tube is closed and the other is connected to a pressure sensor. As each wheel of a vehicle runs over the tube it causes a pressure.

Wireless sensor networks (WSN) are new integrative technologies arising from the development of wireless communication and tiny sensors. WSN is a kind of monitoring networks consisting of a large number of low-cost, power-saving, highly integrative and self-organized sensor nodes and network coordinators. WSNs own broad and valuable application outlook including military, urban management, biomedical treatment, environmental monitoring and remote monitoring of dangerous areas. WSNs installed on roads in a sweeping manner can not only obtain the traffic flow parameters of the entries and exits of intersections, but also of the forks, crosswalks, bus stations and other special places. Therefore, with WSNs covering road networks over a great area, the globe traffic information can be observed in details in the traffic monitoring centre. This trend will certainly bring great breakthroughs in the traffic monitoring technologies.

Typically, sensor nodes are organized as sensing nodes and aggregator nodes. While a sensing node is responsible for sensing data, an aggregator node is used to process data from sensing nodes and send results data to a base station. A base station is used to collect data from the entire sensor network and reports the data to an end user.

The system is made up of three components for detecting and tracking the moving objects. The first component consists of inexpensive off-the shelf wireless sensor devices, such as MicaZ motes, capable of measuring acoustic and magnetic signals generated by vehicles. The second component is responsible for the data aggregation. The third component of the system is responsible for data fusion algorithms.

Figure 2 shows that the top and middle layers of the architecture are consistent to present traffic information network. The bottom layer makes up of WSNs, which are very flexible. With the rapid developing WSN technologies, all kinds of information of the physical world around us will be transferred to the present information system at a fine level and with high speed. As a result, the urban traffic network with distributed parameters will become more measurable and controllable.

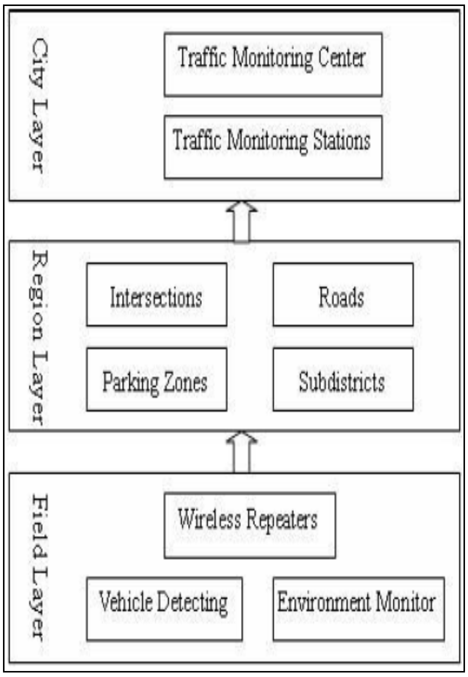

Fig. 2 The Architecture of the Hybrid Mode [2]

The advantage of using WSN:

1) WSN can monitor and evaluate the roads automatically and continuously, with little human effort

2) WSN can work in nights and abominable weather, when there is fog or dust

3) WSN is able to accurately record the traffic flow data of the road for further analysis which is hard for video cameras

4) WSN is becoming cheaper and can be deployed in a fine-grained mode for real time and "real space" traffic monitoring

2. DESIGN

Functional block diagram of the Traffic Monitoring system is shown in Figure 3; the system has mainly two blocks of master node and slave node. Master node consists of ARM based processor capable of performing multitasking operations.

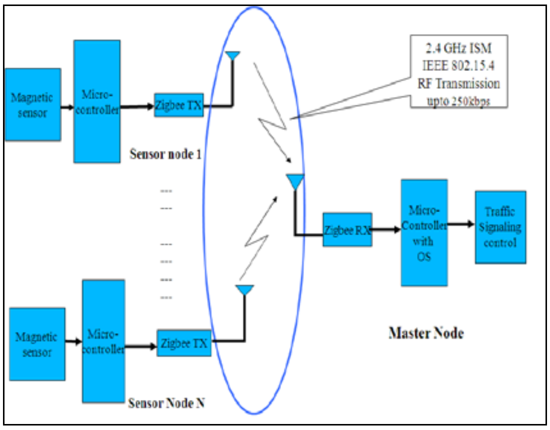

Fig. 3 Block Diagram of Traffic Monitoring System

Slave node consists of vehicle detection sensor and ZigBee RF module. Sensor collects the vehicle detected data and sends to master node through RF module. Based on efficient algorithm Master node will allow the vehicle denser lane to be cleared Traffic Monitoring System block consists of a Junction with 4 Lanes (North Lane, South Lane, East Lane, West Lane). Magnetic Sensors are mounted on each Lane in regular fashion based on efficient sensing of the vehicle.

Slave controller consists of two zones zone-1 and zone-2, Zone-1 is connected to North and West lane sensors and Zone-2 is connected to South and East Lane Sensors. Vehicles passing from these lanes are detected through sensors and sensor data are sending to ZigBee modules connected at two zones. Master node consists of RF Transceiver and Traffic signal controlling is done using efficient algorithm. RF data sent from slave (zone-1 and zone-2) is collected by master depending on the sensor weight active decision is taken as a result the lane with high density is allowed to pass.

3. HARDWARE DESIGN AND IMPLEMENTATION

As shown in Figure 4 high level design of traffic monitoring system consist of a junction where four lanes meets and it is represented as North Lane, South Lane, East lane and West lane. Each lane will be having vehicle detection sensor named as NS (north sensor), SS (south sensor), ES (east sensor), WS (east sensor) in turn the corresponding lane traffic light are represent as TL-N, TL-S, TL-E, TL-W. As algorithm demands it has been sub divided into four lane junction with two zones as zone-1 and zone-2, zone-1 correspond to north and west lane similarly zone-2 corresponds to south and east lane [4].

This section consist of implementing master node which includes ARM processor, ZigBee receiver and Traffic controlling signals as shown in Figure 5. Samsung S3C2440A (ARM920T) based ARM board mini2440 has been used which runs at 533 MHz, has 64M SDRAM, 128M Nand Flash, 2M Nor Flash with BIOS installed, S3C2440 support 2 boot mode Nand Flash boot and Nor Flash boot. Memory map and chip selection is different based on different boot mode. It supports OS porting compatible with Linux 2.6, Android and WinCE [5].

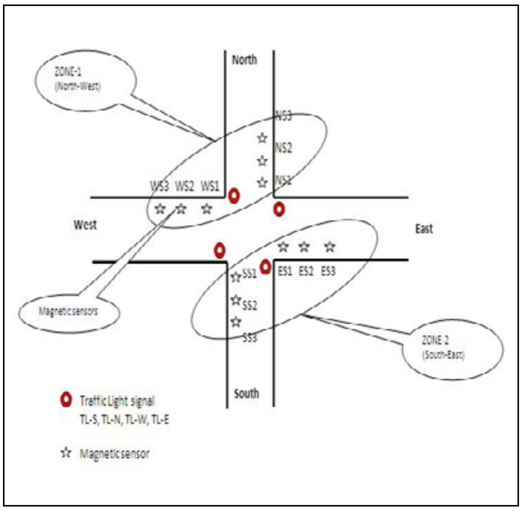

Fig. 4 High Level Design of the Traffic Monitoring System

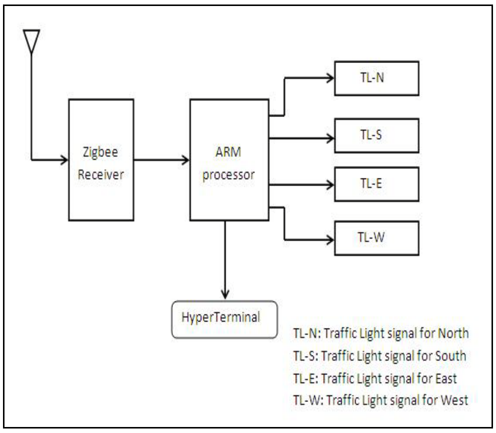

Fig. 5 Block Diagram of Master Node

Master node flow chart has been shown in Figure 6a to 6d. First all the initializations for the port pins are done and other necessary settings like UART, sensor port are done. Next step is to receiving RF data from zone-1 and zone-2 slave nodes, there is particular format followed in recognizing the exact zone data, if start of packet is '$' then data belongs to zone-1 and if start of packet is '#' then data belongs to zone-2.Now once data is received, master controller will decode the packet and calculate for first maximum weighted lane and then second maximum weighted lane. As a result the lane particular to first maximum lane is allowed first and then second maximum lane is allowed to pass next.

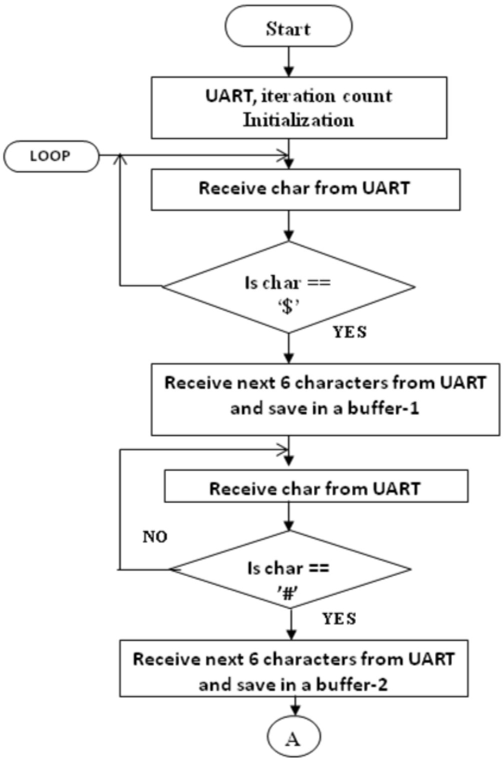

Fig. 6a Master Node Flow Chart

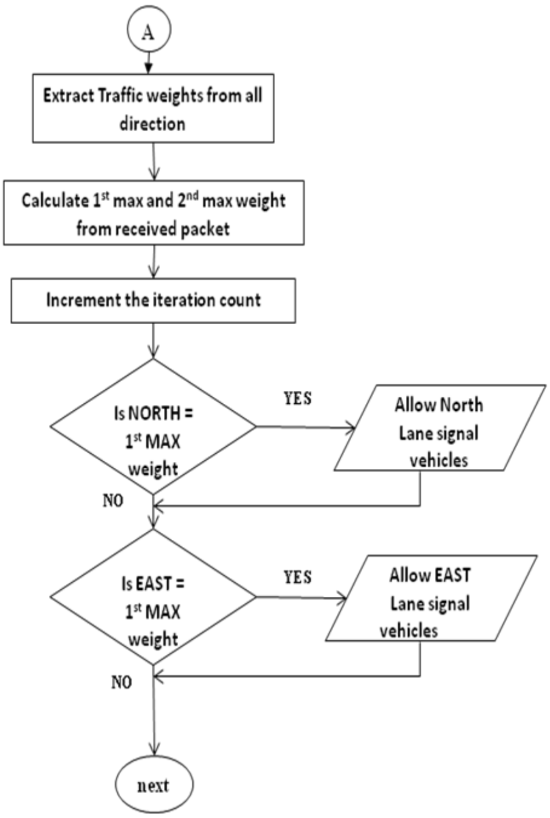

Fig. 6b Block Diagram of Master Node

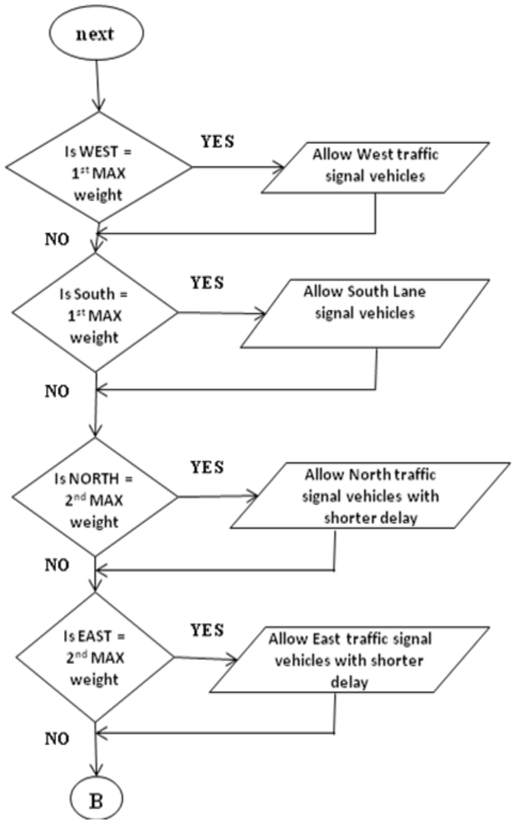

Fig. 6c Block Diagram of Master Node

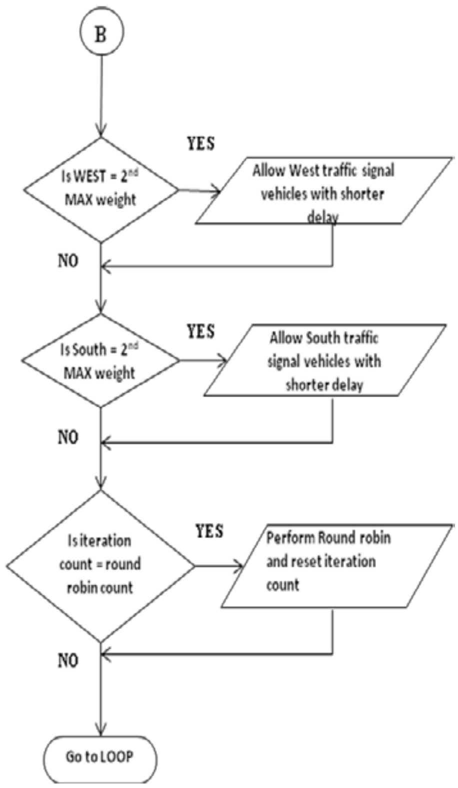

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Fig. 6d Block Diagram of Master Node

3.1 Algorithm Implementation

This section explains about the algorithm implemented in performing efficient traffic monitoring and signaling. As explained in earlier section the system consist of three weighted sensors located in each lane and there is traffic signal (Red, Yellow, Green) corresponding to each lane. By default the traffic signal passing sequence followed at the junction is North, East, West and South lane i.e ‘N’ ‘E’ ‘W’‘S’ this is shown in Figure 8 and 9 representing Round robin sequence and weighted round robin. Figure 7 shows the zones and its cycles of traffic flow for sender and master data reception with round robin and weighted round robin algorithm.

Fig. 7 Round Robin Algorithm and Weighted Round Robin Realizations

3.2 Schematic Circuit Diagram for Master Node

The schematic circuit diagram of the Traffic monitoring system for master node is shown in Figure 10 and 11. It consist of connecting ZigBee module through UART port from ARM board and traffic signal lights are connected to port pins of ARM board.

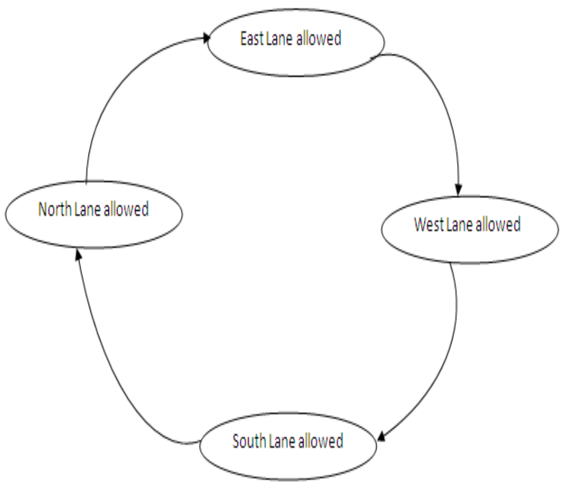

Fig. 8 Round Robin Algorithm

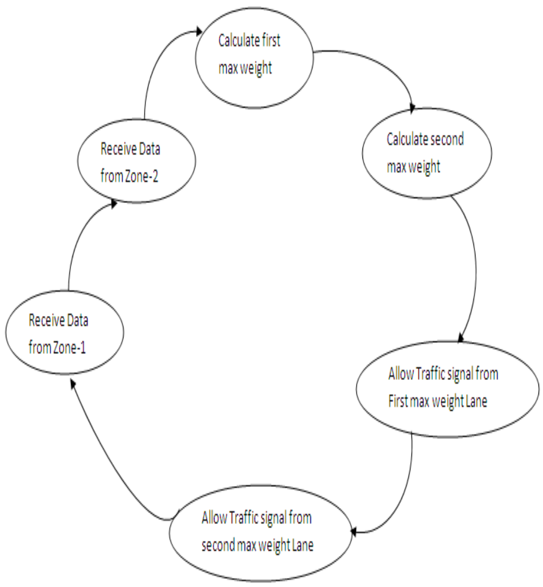

Fig. 9 Flow Diagram Representing Weighted Round Robin Algorithm

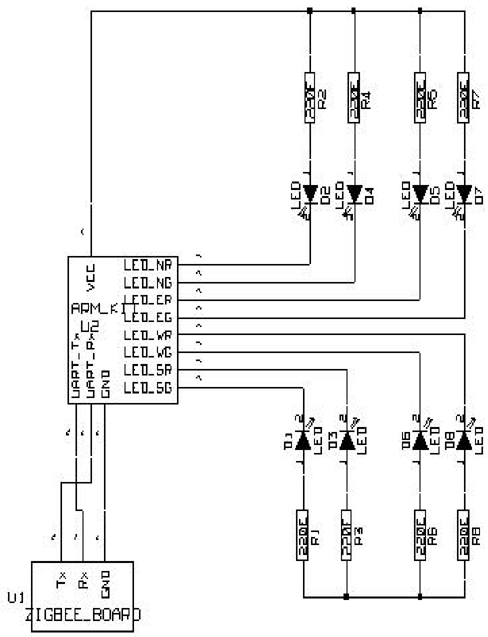

Fig. 10 Schematic Circuit Diagram for Master Node

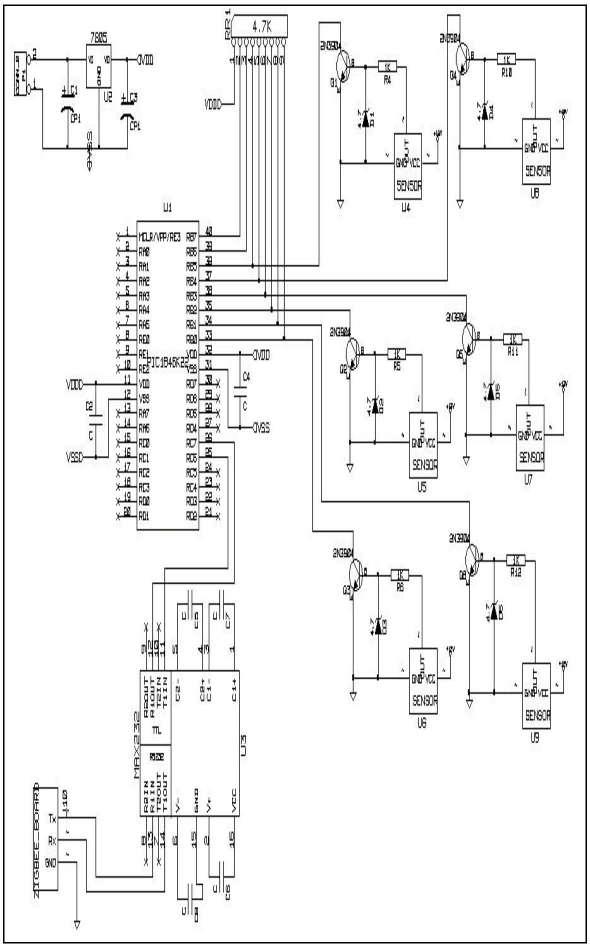

Fig. 11 Schematic Circuit Diagram for Master Node

4. RESULTS AND DISCUSSIONS

Figure 12 shows slave zone node along with sensor and added weight, there are three magnetic sensors which are in yellow color as shown which is interfaced to zone-1 PIC microcontroller through GPIO, when any metal piece is detected it sends the data. For experimental process metal washer and metal slab piece is used.

Once the complete set-up is ready and working properly, we can ensure the wireless module to be working in good condition by checking and diagnosing through HyperTerminal set-up. The master will schedule the signaling process of allowing the vehicles based on sensor input. Figure 14 shows North, South, East, West Weight and its corresponding traffic light signals showing in HyperTerminal and Figure 15 shows the zone-1 one received data on hyperterminal.

Vehicles are been sensed through sensor laid on pavement from slave node, it frames the collected RF data and sends to the master for further processing the RF data been collected is shown in Figure 13. Based on the weights shown the Master controller will allow the signal for the lane in sequence of East lane then South Lane, then North Lane, then West Lane, this sequence is followed for four cycles then one Round Robin is executed [3].

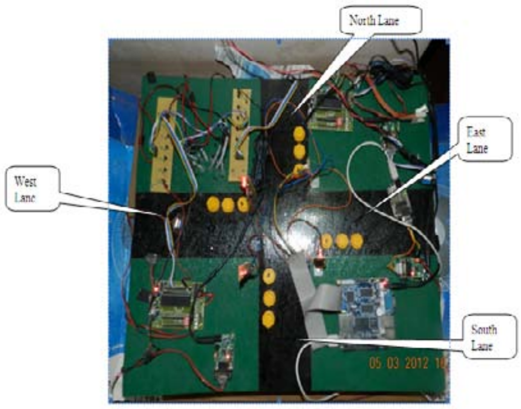

Fig. 12 Snap Shot of the Complete System Setup

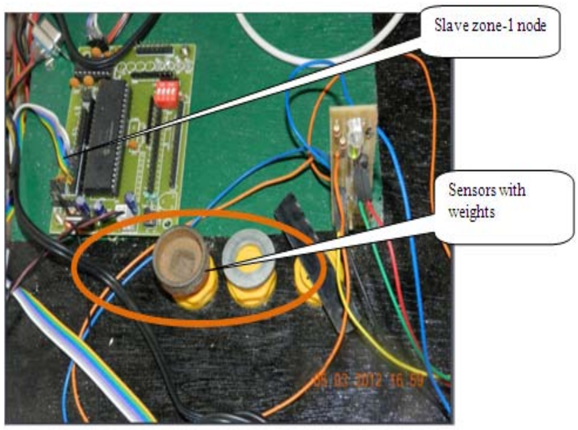

Fig. 13 Slave Node Along with Weighted Sensor

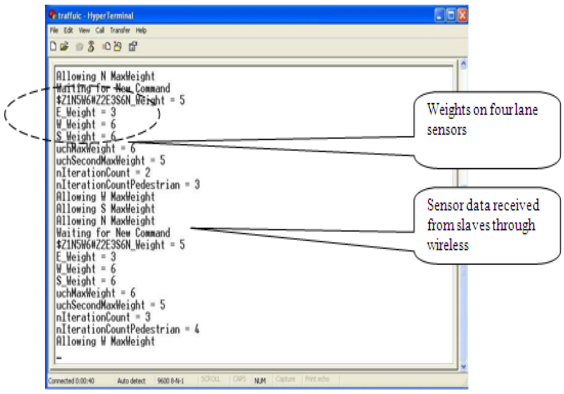

Fig. 14 Hyper Terminal Result

As explained the process of performing average queuing theory, average waiting time and performance throughput had been calculated. To represent the calculated performance and waiting time between RR and WRR system process graphs are been plotted as shown below.

Figure 14 shows the sensor data at the hyperterminal of the Zone-1 sensor data.

The below equations are been used to plot the graph

Average arrival rate lambda λ = (average input / Cycle time) -------------- (1)

Average input =1/2 Peak input -------------- (2)

Average waiting time Wi = Average Left over vehicles / lambda λ -------------- (3)

Cycle time is constant for RR and WRR since the average signaling duration is same for both Figure 16 shows the graph for average waiting time in the system for round robin and weighted round robin implementation on X-axis represents average arrival rate vehicles per second and Y-axis represents average waiting time per seconds.

Similarly system throughput graph is also plotted as shown in Figure 17, throughput is calculated by using equation shown below

Throughput of system = average No of vehicle allowed / Average arrival rate lambda λ ------------- (4)

5. CONCLUSIONS

Traffic Monitoring system for four Lane Junction has been implemented successfully using an efficient wireless sensor networked algorithm (weighted Round robin) on master-slave controller. The conclusions are:

- Vehicle density is one of the main metrics used for assessing road traffic condition
- In the traffic information system, the flow rate is obtained by counting the number of vehicles that pass through a detection device, such as an inductive loop detector or a surveillance camera, over a period of time
- Manual traffic signal control can be overcome
- Wireless nodes can be used to send collected vehicle detection sensor data
- Using the algorithm developed, waiting time at traffic signal junction for commuter can be reduced

The following enhancements of the system can be considered for future:

- Ambulance and VIP vehicles priority should be considered by using wireless technology at master node
- Placement and Installing the clusters of magnetic sensor at road pavement in order to detect the vehicle accurately
- Vehicle detection method can be improved in order to identify what kind of vehicle it is and length of vehicle (car, truck, etc.)

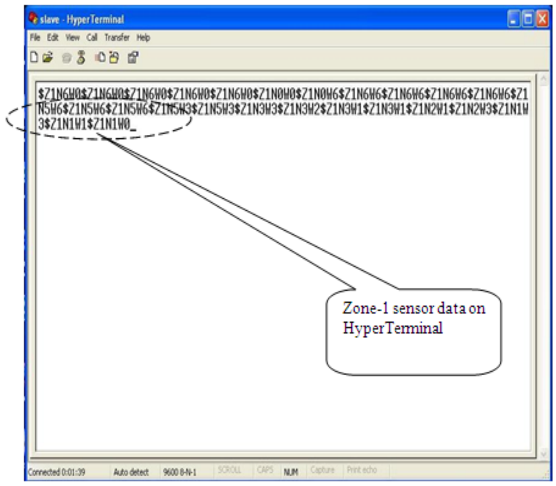

Fig. 15 Zone-1 Wireless Sensor Data

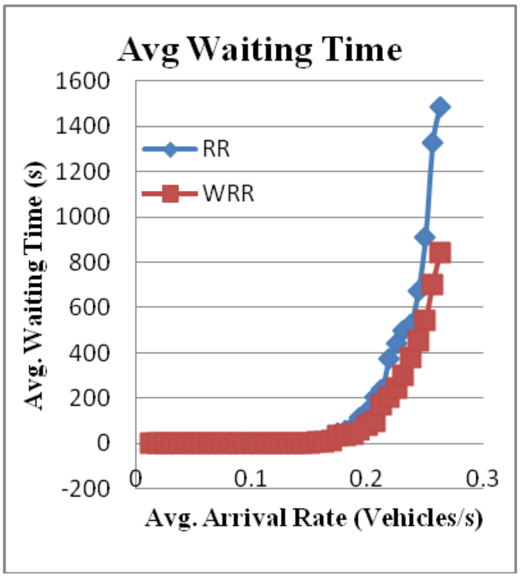

Fig. 16 Comparison based on Average Waiting Time

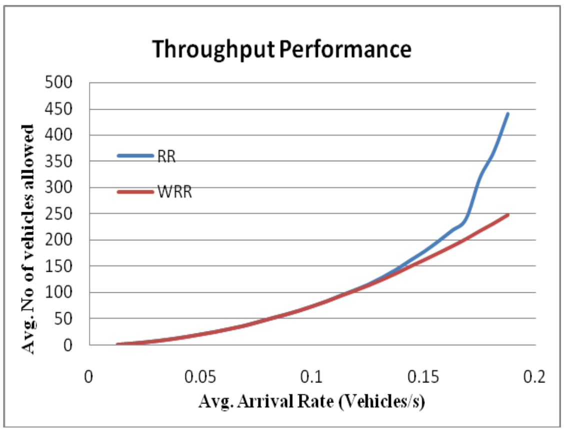

Fig. 17 Throughput of the Developed System

6. REFERENCES

[1] Carlos S., *An Investigation in the Use of Inductive Loop Signatures for Vehicle Classification, Research Reports*, Institute of Transportation Studies, PATH, University of California, Berkeley, 2000.

[2] Wallin Englund, *RF in Wireless Sensor Network, Technical Report, Department of Signals and Systems*, Chalmers University of Technology, Sweden, 2004.

[3] Cirronet, *White paper on ZigBee Wireless Transceiver Engineering Options*, April, 2005.

[4] Unknown, *Datasheet for CC2500 Based Wireless Module*, www.robosoftsystems.co.in, Retrieved on 12th September 2010.

[5] Unknown, *Mini2440 Friendly ARM Board*, www.friendlyarm.net, Retrieved on 3rd March 2011.