Low-power TPMS Data Transmission Technique Based on Optimal Tire Condition

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Abstract—**Tire Pressure Monitoring System (TPMS), which is a type of wireless communication device used in vehicles, is a safety aid system designed to prevent tire-related accidents in advance by regularly checking tire pressure and temperature and notifying the driver about any abnormality through its display. TPMS sensor unit in a tire contains sensors to measure the temperature and pressure and transmits the measured data to the signal processing unit in a vehicle via wireless communication. For the conventional TPMS, there is unnecessary power consumption in the sensor unit because of continuous transmission of the measured data from the tire to the signal processing unit at a regular interval. In this paper, we propose the low-power TPMS communication technique in which the signal processing unit in the vehicle transmits optimal tire pressure and threshold values based on the road condition and external temperature to the sensor unit in the tire. The sensor unit compares the measured data value with the optimal tire pressure value received from the signal processing unit and it sends the measured tire pressure data to the signal processing unit only if the difference between the values exceeds the threshold value. When the difference between both values is smaller than the threshold value, the sensor unit recognizes it as normal mode and transmits a normal mode bit to the signal processing unit. The performance of the proposed low-power TPMS communication technique is verified through computer simulation example.**

Keywords-Tire Pressure Monitoring System (TPMS); Low-Power; Optimal Tire Pressure Value.

I. INTRODUCTION

Tire pressure may become lower or higher comparing with the standard condition, due to certain circumstances during vehicle operation, resulting in serious accidents. The majority of drivers may not be able to detect such risk in advance, which often leads to a major accident [1][2]. In order to prevent this problem, TPMS was developed and there have been active studies to develop high-performance TPMS. TPMS can be defined as a safety aid system that displays the information about temperature and pressure from the sensors attached to the tire wheel or valve to the driver so that the driver can check the tire condition in real time and thus prevent the tire-pressure related accident in advance [3][4][5][6][7]. Currently, many countries are promoting to mandate or have already mandated vehicles to be equipped with TPMS. A representative example that has led to mandating TPMS due to an accident in which some of the tires supplied by one of the world's largest tire manufactures had ruptured while driving due to lower air pressure, leading to many casualties. With this incident, the United States legislated about TPMS on vehicles in 2003 and has mandated to install TPMS on every vehicle since September 2007 [8][9]. In Korea, it is mandatory to install TPMS on all passenger cars and vans less than 3.5 tons to be manufactured after January 1, 2013.

Most of the currently TPMSs need to be replaced when the battery for the sensor unit is exhausted, making it an urgent need to develop the low-power TPMS. To solve this problem, we propose in this paper a low-power TPMS wireless communication scheme based on a duplex communication. In the proposed scheme, the signal processing unit in the vehicle saves the information of optimal tire pressure values for road conditions and external temperature in its database, measures the road conditions and the external temperature using sensors attached to the bottom of the vehicle, selects optimal tire pressure and threshold value from the database, and sends them to the sensor unit. Instead of transmitting data of the tire pressure and temperature at a certain interval (for example, per second) to the signal processing unit, the sensor unit sends the measured data only when the tire pressure is not normal that the difference between the measured pressure in sensor unit and the optimal pressure transmitted from signal processing unit is greater than the threshold for the instant external condition. As a result, the sensor unit attached to the tire may consume much less power than the conventional TPMS.

The rest of this paper is organized as follows. In Section II, the system model for the low-power TPMS wireless communication is presented. The data structure for the proposed system is described in Section III and a flow-chart for low-power TPMS wireless communications is presented in Section IV. In Section V, we provide computer simulation results to demonstrate the performance of the proposed system. Finally, conclusions are outlined in Section VI.

II. SYSTEM MODEL FOR LOW-POWER TPMS WIRELESS COMMUNICATION

In the low-power TPMS wireless communication scheme proposed in this section, the signal processing unit in a

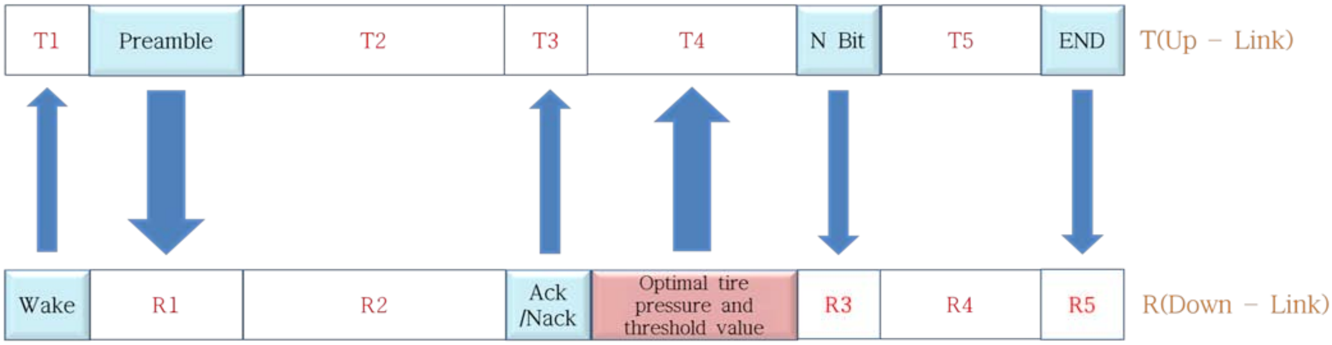

Figure 1. Data structure for low-power TPMS wireless communications based on duplex communications (Normal Mode).

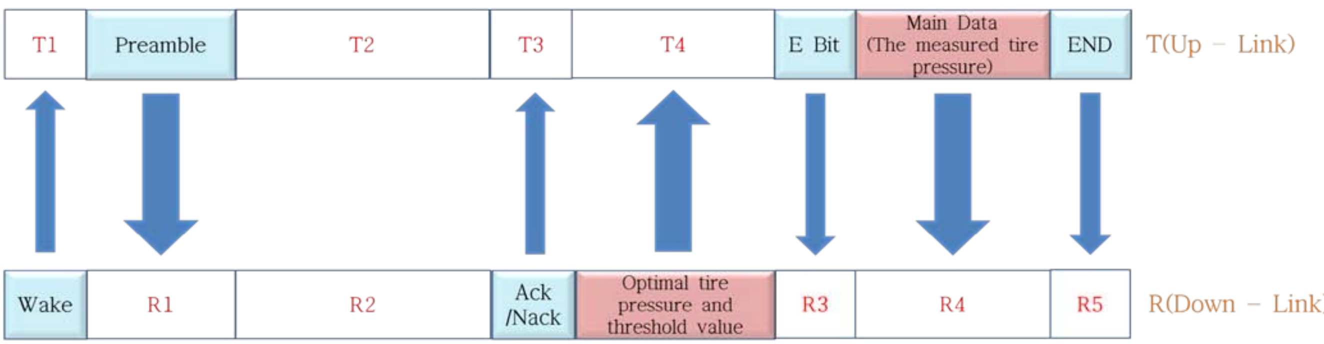

Figure 2. Data structure for low-power TPMS wireless communications based on duplex communications (Emergency Mode).

vehicle transmits the tire pressure and threshold value suitable for the road condition and the external temperature to the sensor unit on the tire, and the sensor unit compares the measured data with the optimal tire pressure value received from the signal processing unit and sends the measured tire pressure data to the signal processing unit only if the difference is bigger than the threshold value. The sensor unit compares the measured tire pressure data with the optimal tire pressure and threshold value using (1)

$$|x - a_i| \gtrless \beta, \quad i = 1,2,3,4 \tag{1}$$

where, x is an optimal value for the tire pressure suitable for the road condition and external temperature, α_i means the tire pressure measured at the i th tire, and β is a threshold value.

For example, if the threshold value β to determine the tire condition is set to 3 and the optimal pressure x for road conditions and external temperature to 40Psi, and the actually measured tire pressure α_i is 35Psi, the difference between the optimal tire pressure and the measured tire pressure is 5, which exceeds the preset threshold value of 3. In this case, the sensor unit determines the tire condition as dangerous state and the sensor unit operates in the emergency mode to send the measured tire pressure to the signal processing unit at a regular interval (for example, every second). For another example, assuming that the preset threshold value β and the optimal tire pressure x for road conditions and external temperature are the same as in the first example, if the measured tire pressure α_i is 38Psi, the difference between the optimal tire pressure and the measured tire pressure would be 2. As it is smaller than the preset threshold value 3, the sensor unit determines that the tire pressure is in normal state. In this case, the sensor unit operates in the normal mode, and sends N bit for normal mode to the signal processing unit only when the optimal tire pressure and threshold value are received from the signal processing unit (e.g., per minute).

III. Data Structure for Low-Power TPMS Wireless Commiunication

In this section, data structures for the low-power TPMS wireless communications based on duplex communication are proposed. Fig. 1 and Fig. 2 show data structures for normal mode and emergency mode for the proposed low-power TPMS wireless communication technique, respectively. Most of the currently used TPMSs use simplex wireless communication mode, in which the data measured at the sensor is transmitted periodically (e.g., per second), resulting in unnecessary power consumption. The data structure proposed in this paper transmits the optimal tire pressure data periodically (e.g., per minute) from the signal processing unit to the sensor unit, and transmits the measured pressure data from the sensor unit to the signal processing unit. It switches to emergency mode only if the measured data is larger than the preset threshold value. This allows saving the power consumption of the battery installed in tires and thus the proposed TPMS communication technique is much more efficient than the conventional TPMS in terms of power management.

A. Data Structure for Normal Mode

Components of the low-power TPMS wireless communication data structure for normal mode are defined as follows:

- Wake: a bit for requesting the operation of the sensor unit.
- Preamble: data for channel estimation, signal-to-interference and noise ratio (SINR) estimation, synchronization, etc.
- Ack/Nack: Ack bit means that the transmitted data is effective and Nack bit means that the transmitted data is non-effective (for example, transmitting ‘1’ for Ack and transmitting ‘0’ for Nack).
- Optimal tire pressure and threshold value: optimal tire pressure and threshold value selected from the database of measured road conditions and external temperature sent to the sensor unit.
- N Bit: informing the normal state bit.
- END: information bit for the end of the transmission of the main data.
- T1: blank in the sensor unit for receiving Wake bit.
- T2: blank in the sensor unit for waiting the transmission of the preamble data for other tires.
- T3: blank in the sensor unit for receiving Ack/Nack bit from signal processing unit.
- T4: blank in the sensor unit for receiving data of the optimal tire pressure and threshold value.
- T5: blank in the sensor unit between transmitting N bit and transmitting END bit.
- R1 : blank in the signal processing unit for receiving the preamble data.
- R2 : blank in the signal processing unit for waiting the transmission of the preamble for other tires.
- R3 : blank in the signal processing unit for receiving N bit.
- R4 : blank in the signal processing unit between receiving END bit and receiving N bit.
- R5 : blank in the signal processing unit for receiving END bit.

B. Data Structure for Emergency Mode

Components of the low-power TPMS wireless communication data structure for emergency mode are defined as follows (terms already defined in the normal mode structure are omitted):

- E bit: informing the emergency state bit.
- R3: blank in the signal processing unit for receiving E bit.

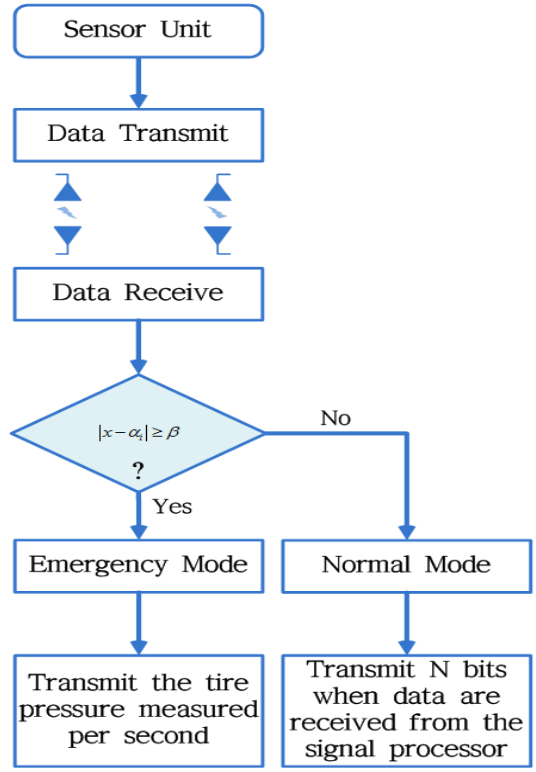

Figure 3. Flow-chart for low-power TPMS wireless communications based on duplex communications.

- R4 : blank in the signal processing unit for receiving the main data.

The proposed low-power TPMS wireless communication system based on duplex communications repeats transmitting /receiving the above-mentioned data between the sensor unit and the signal processing unit as needed.

IV. Flow-Chart for Low-Power TPMS Wireless Communications

This section presents a basic flow-chart for the proposed low-power TPMS wireless communication based on a two-way communication, as shown in Fig. 3. Based on the data received from the signal processing unit, if the left side of (1) is bigger than the preset threshold value, it is deemed dangerous condition, causing TPMS to operate in an emergency mode. In this case, the tire pressure data is transmitted to the signal processing unit every second the same as in one-way wireless communications, so that the tire pressure can be checked every second. On the other hand, if the left side of (1) is smaller than the preset threshold value, it is deemed normal condition, leaving TPMS to operate in normal mode. In this case, the sensor unit transmits N bit for normal condition to the signal processing unit, only when receiving the optimal tire pressure and threshold value data from the signal processing unit, instead of transmitting the tire pressure data every second.

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V. COMPUTER SIMULATION

In this section, we present the results of computer simulation to demonstrate the performance of the low-power TPMS wireless communication technique based on duplex communications, comparing with the conventional one-way TPMS communication scheme. For the first simulation, we assume that the length of preamble and main data are 56 bits and main 32 bits, respectively, thus the total length of TPMS data frame is 88 bits. It is also assumed that the subject vehicle operates two hours a day in a 30 days period. For the conventional TPMS wireless communication scheme, it is assumed that the sensor unit transmits a data frame every second in consideration of emergency. For the proposed scheme, it is assumed that the signal processing unit transmits the optimal tire pressure and threshold value to the sensor unit once per minute. Fig. 4 shows the comparison of the total number of bits transmitted in the two systems when the tire condition was normal for the considered period. As shown in the figure, for the 30 days period, the total number of bits transmitted in the proposed system is much smaller than in the conventional one-way TPMS system. Fig. 5 shows the comparison of the total number of bits transmitted in the two systems, with the assumption that the systems operated in emergency mode for approximately 30 minutes as the tire fault was detected on the 15th day. As shown in the figure, although the number of bits transmitted in the proposed system is increased as it operated in emergency mode for 30 minutes on the 15th day, it is much smaller than the number of bits transmitted in the conventional one-way TPMS system.

Fig. 6 shows the comparison of power consumption in the two systems for 30 days, assuming the transmitted power per bit is 0.1μW and the tire condition is normal. As shown in the figure, the total power consumption for the sensor unit in the proposed system is significantly lower than the conventional system. Fig. 7 shows the comparison of power consumption in the two systems with the assumption that the transmitted power per bit is 0.1μW and the systems

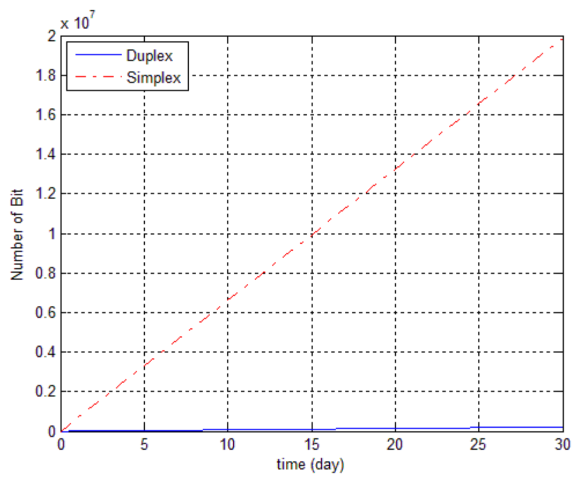

Figure 4. Number of bits versus duration for the proposed and conventional TPMS communiatoin tehcniques for normal mode

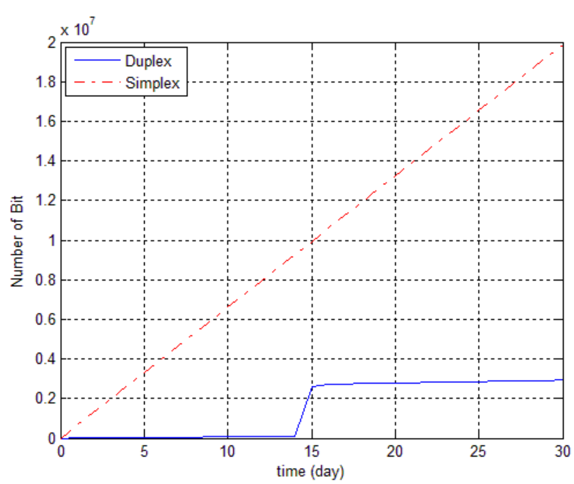

Figure 5. Number of bits versus duration for the proposed and conventional TPMS communiatoin tehcniques for considering the emergence mode

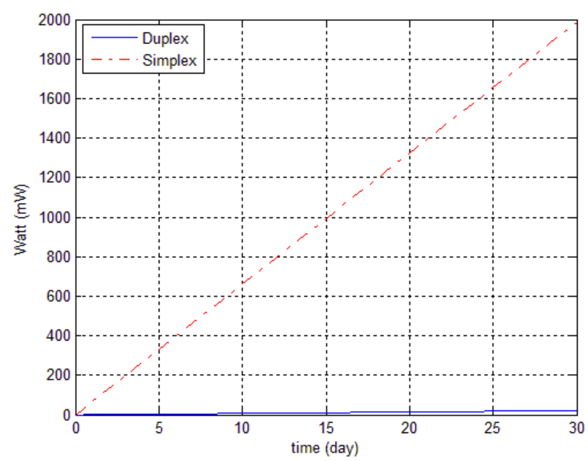

Figure 6. Power consumption versus duration for the propsed and convetional TPMS communications technues for normal mode.

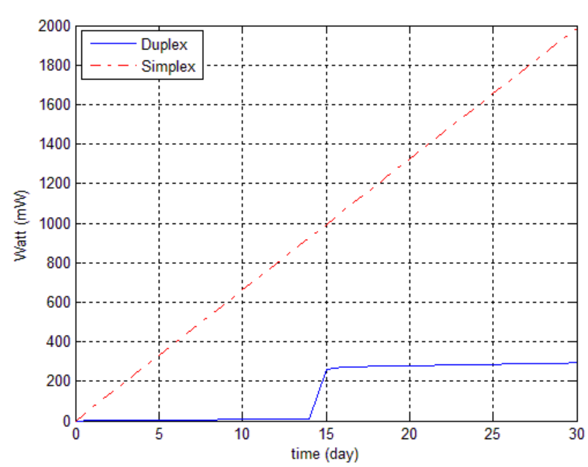

Figure 7. Power consumption versus duration for the proposed and conventional TPMS communiatoin tehcniques for considering the emergence mode

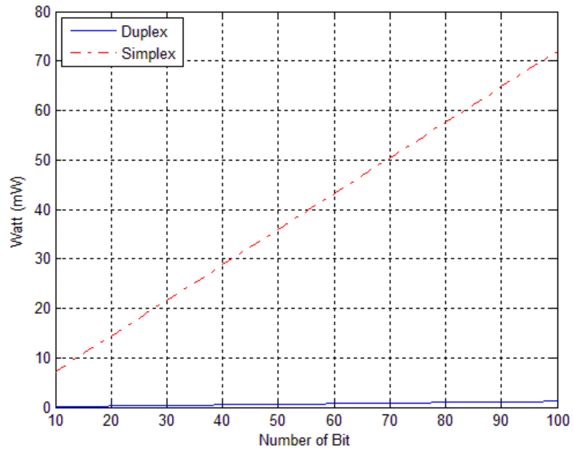

Figure 8. Power consumption versus number of bits for the proposed and conventional TPMS communiatoin tehcniques for normal mode

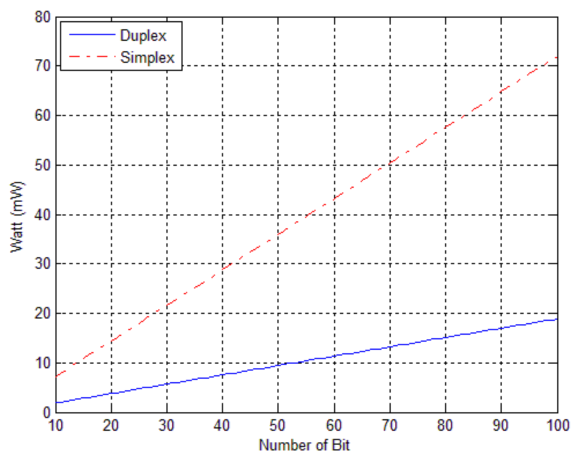

Figure 9. Power consumption versus number of bits for the proposed and conventional TPMS communiatoin tehcniques for considering the emergence mode

operated in emergency mode for 30 minutes as a tire fault was detected on the 15th day. The figure shows that, although the power consumption of the proposed system is increased as the system operated in emergency mode for 30 minutes on the 15th day, it is significantly lower than that of the conventional system for the considered duration.

Fig. 8 shows the comparison of power consumption versus the length of data frame transmitted from the sensor unit to the signal processing unit, in the two systems, while driving two hours, assuming that the transmitted power per bit is 0.1μW and the tire condition is normal. As shown in the figure, power consumption for the proposed method varies with the changing the length of the data frame (number of bits) and is significantly lower than the power consumption for the conventional method. Fig. 9 shows the result of the compared power consumption for the two systems depending on the changing length of the data frame. It is assumed that the transmitted power per bit is 0.1μW, the vehicle runs for two hours, and the vehicle has run in the emergency mode for 30 minutes. As shown in Fig. 9, while operating in the emergence mode for 30 minutes, the power consumption of the proposed system is increased compared with that in Fig 8., but it is significantly lower than the power consumption of the conventional one-way TPMS method. As verified through the simulation, we observe that it is more efficient to use the proposed system as it transmits significantly less data bits and thus significantly saves the power of the battery installed in the sensor unit, unless it always keeps operating in emergency mode. However, the proposed system requires significantly small power consumption comparing with the transmitted power for comparison of the difference value between the optimal and the measured pressure, and the threshold value.

VI. CONCLUSION AND FUTURE WORK

As the casualties caused by tire accidents increased, TPMS has attracted much attention worldwide. Since TPMS has the average life of seven years and when the battery life is over, the TPMS itself needs to be replaced, it is urgently needed to develop a low-power TPMS sensor unit with similar life-time to a vehicle. In this paper, in order to extend the battery life-time of the conventional TPMS, we proposed a new TPMS wireless communication technique, in which the sensor unit installed in a tire receives the optimal tire pressure and threshold value for road conditions and external temperature from the signal processing unit installed in the vehicle and transmits the measured tire pressure data to the signal processing unit only when it is needed. When the difference between the measured tire pressure and the optimal tire pressure is not greater than the threshold value, the sensor unit transmits one bit indicating normal condition to the signal processing unit, instead of periodically transmitting the measured pressure vale, which helps reduce the power consumption of the sensor unit. The performance for saving power consumption of the proposed system was illustrated through simulation examples. Currently, we are studying for the reduced interelement spacing of antennas for the TPMS beamformer.

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