

Infusion Monitoring Communication Model of Smart Home Based on Coloured Petri Net

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Abstract: When patients need to be for infusion at home, there is no central control server in hospital, and it is not possible to add additional monitoring equipment; at the same time, there may not be a special person to care for patients. The infusion monitoring communication model of smart home based on coloured Petri net, which is proposed in this paper, can use smart mobile phone to construct an adaptive infusion monitoring system at home. The model can make infusion alarm module automatically search for smart mobile phone terminals in a WiFi network, complete the search, identification, monitoring and other functions. It will constitute a smart phone infusion monitoring network so that infusion online monitoring could effectively be completed at home without adding additional equipment. The simulation result shows that regardless of whether there is a packet loss, as long as there is a smart mobile phone terminal and the corresponding infusion alarm module in the network, the model can make the infusion alarm module to realize automatic search function and infusion monitoring function, and provide better medical service for the smart home.

Keywords: Infusion monitoring, Coloured Petri net, Smart mobile phone, Smart home.

Introduction

At present, when the patients need the infusion treatment at home, it usually uses artificial method to adjust the drop speed of liquid. This way is not accurate enough, and not convenient. When the infusion is abnormal or complete, it is not easy to be discovered in time. All these factors will cause medical risks. Moreover, family care workers are often not professionals. In the care of patients, he may also complete other work so that he could often forget to pull the needle in a timely manner. How to make patients get better medical care at home is a problem that needs to be solved.

In 2018, the developed Generalized Net (GN) model [10] provides a framework that may be very useful for the primary care. The intelligent technique [4, 11] has also been widely used in the medical field. A medical infusion monitoring system based on a controller area network (CAN bus) is proposed in [12], which can make the computer complete the monitoring and control of intelligent nodes by CAN bus. Based on photoelectric technology, single-chip technology and wireless communication technology, a distributed intelligent monitoring system for the infusion is designed in [1]. At the end of infusion, the system generates automatic alarm prompt, and it owns high detection accuracy, fast response time and so on. Georgieva [5] proposes a GN-model of mechanical treatment of waste water, makes the individual qualitative and quantitative characteristics of the treated water before and after going through specific facilities to ensure optimal conditions for conducting the treatment processes. Moreover, the GN-model would also contribute to the more effective operation of the subsequent. Yang et al. [13] design a set of micro infusion monitoring system for community medical treatment. It can

not only achieve the infusion alarm at the end of, but also can use the hospital's existing network to achieve remote monitoring. Diao et al. [3] design a set of venous infusion monitoring system that is composed of the host and the monitoring center. It can effectively monitor the process of infusion, and can automatically prompt to replace the liquid. Peng et al. [8] use smart mobile phone as a client that can real-time display, monitor the infusion status and physiological parameters of the patients through wireless LAN and the central monitoring server in hospital. Jia et al. [6] achieve the automatic monitoring of the infusion process based on serial communication. Liu et al. [7] design and construct a network infusion monitoring system based on RS485 bus. Deng et al. [2] design and implement an infusion monitoring alarm system based on Internet of things technology. The system uses nRF905 module to implement the data transmission. In the same year, Petkov and Sotirov [9] describe a GN-model that can be used to solve the “stability-plasticity dilemma”.

The infusion alarm monitoring system in the mentioned above investigations is mainly used in the hospital to achieve infusion monitoring. However, if competing infusion in a patient's home there may not exist in the host computer, there is no central monitoring server in hospital, it is impossible that adds additional monitoring equipment, and there may not be a special person to care for patients. At the same time, in the above monitoring system, it only completes wired or wireless transmission of the alarm signal, and does not consider the signal errors and lost that impact on monitoring system. And it also did not consider how to implement the adaptive selection of the control terminal, and specific interaction process of communication. Moreover, it is not practical to monitor the infusion through the computer in home care; therefore. So the infusion monitoring system in the mentioned above investigations does not apply to the needs of infusion monitoring for smart home.

The paper proposes the infusion monitoring communication model of smart home based on coloured Petri net, which can use smart mobile phone to construct adaptive infusion monitoring system at home. It can automatically search for smart mobile phone terminal in a same WiFi network, and complete the search, authentication, monitoring and other functions. And infusion online monitoring could effectively be completed at home without adding additional equipment.

Infusion monitoring communication model based on coloured Petri net

Framework of infusion monitoring system at smart home

Infusion monitoring system at smart home is composed of the smart mobile phone terminal, wireless router (WiFi) and infusion alarm module, and the smart mobile phone terminal achieves the monitoring of multiple infusion alarm modules by the wireless router. The smart mobile phone terminal and wireless router are for two-way connection, wireless router and the infusion alarm module are also for two-way connection, as shown in Fig. 1.

Infusion alarm module comprises the liquid level detection circuit, key module, wireless transceiver module, micro controller, alarm circuit and storage, which liquid level detection circuit and micro controller are connected, key module and micro controller are connected, micro controller bidirectionally connects wireless transceiver module, micro controller bidirectionally connects storage, micro controller is connected with the alarm circuit, the storage saves the module identification ID of infusion alarm module in advance, as shown in Fig. 2.

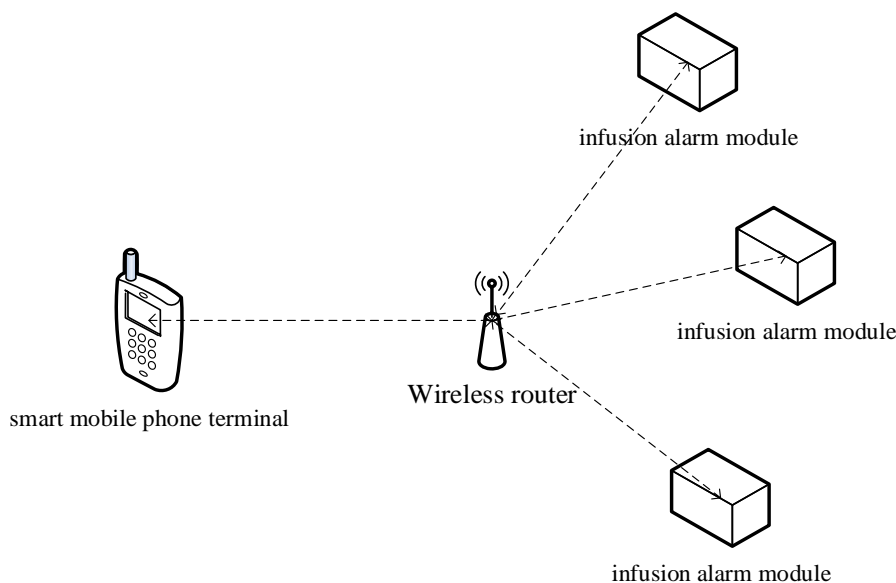


Fig. 1 Infusion monitoring system

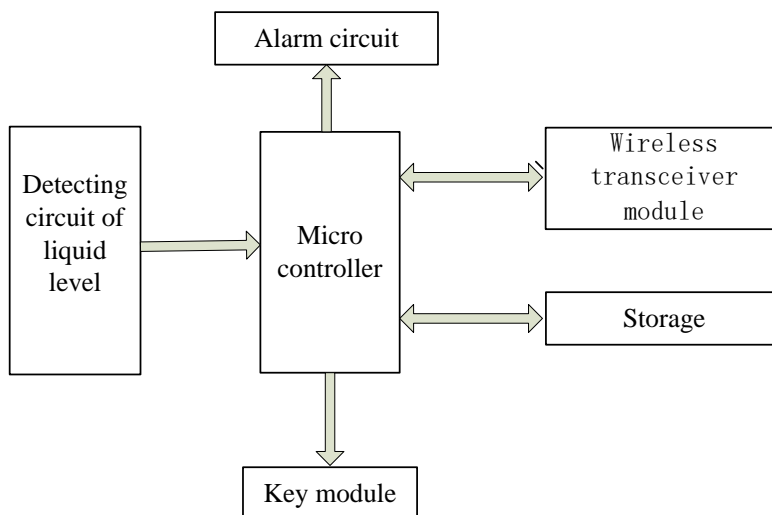


Fig. 2 Infusion alarm module

When you need to use some infusion alarm module to monitor the process of infusion, you can start the smart mobile phone terminal that will store all the infusion alarm module information in its module information table (including the module identifies ID, authentication, alarm status), and the module identifies ID of each infusion alarm module is not the same. The module information table of smart mobile phone terminal is shown in Table 1. At the same time, through the key module of infusion alarm module, monitoring signal is sent to the micro controller of infusion alarm module. After micro controller receives the monitoring signal, through the wireless transceiver module it will automatically add the wireless local area network that wireless router has established. Then micro controller readouts the module identifier ID from the storage of infusion alarm module, generates discovery packet, and sends the discovery packet by broadcast. Through the discovery packet, the infusion alarm module can automatically find legitimate smart mobile phone terminal. After the authentication is passed, the infusion alarm module can obtain the IP address and the port number of the smart mobile phone terminal.

Table 1. Module information table

Field name	Field length
Module identifier ID	2 Bytes
Authentication	2 Bytes
Alarm status	1 Byte

When the infusion alarm module detects that the fluid reach the warning line, through the wireless transceiver module it will establish a TCP connection between the infusion alarm module and selected smart mobile phone terminal. Then notify the smart phone terminal by sending alarm packet, the home nursing staff will deal with.

After completion of the infusion, the key module of infusion alarm module will send exit signals to the micro controller. After micro controller receives exit signals, it will read the module identifier ID from the storage, generate exit packet. And through wireless transceiver module a TCP connection will be established between the infusion alarm module and the smart mobile phone terminal. After the connection is built, the infusion alarm module will send the exit packet. After receiving the exit packet, the smart mobile phone terminal will clear the stored alarm status information, and remove the TCP connection between them.

Packet format

The packet type used in the infusion monitoring communication model are discover packet, discover response packet, alarm packet, alarm response packet, exit packet and exit response packet. The above packet format is shown in Table 2, and the value of packet type is shown in Table 3.

Table 2. Packet format

Field name	Field length
Packet type	1 Byte
Module identifier ID	2 Bytes
Alarm state	1 Byte
Authentication	2 Bytes
IP address	4 Bytes
Port number	2 Bytes
CRC check code	2 Bytes

Table 3. Packet type

Packet type	Value
Discover packet	0x01
Discover response packet	0x02
Alarm packet	0x06
Alarm response packet	0x07
Exit packet	0x08
Exit response packet	0x09

Among them, discover packet and discover response packet as UDP packet data are encapsulated into UDP packets for data transmission. And alarm packet, alarm response packet, exit packet and exit response packet as in TCP packet data are encapsulated into TCP packets for data transmission. When alarm state is equal to 0, it indicates no alarm;

stores the discover response packet that the channel needs to send; the place S7 stores the correct discover response packet that the infusion alarm module receives; the place S9, S11 and S12 stores the discover packet that the infusion alarm module possibly needs to send again; the place S10 stores the discover response packet that the infusion alarm module receives.

In this model, the packet composite colour is $\langle \text{packet type colour, module identifier ID colour, alarm state colour, authentication colour, IP address colour, port number colour, CRC check code colour} \rangle$ that is expressed as $\langle Z_1, Z_2, \dots, Z_7 \rangle$. Assuming that packet composite colour of token on place S1, S2, S4, S5, S6, S7, S9, S10, S11, S12 are expressed as $c, d, e, f, g, l, m, u, v$ and w .

Definition 1 (ignition rule of transition T1)

If tokens exist in place S1 and $P_{r1}c = 1$, the transition T1 ignites, and the place S1 will consume a token after igniting, and S2, S9, S11 will respectively add a token; and $P_{ri}d = P_{ci}c$, $P_{ri}m = P_{ri}c$, $P_{ri}v = P_{ri}c$, $1 \leq i \leq 7$. The infusion alarm module will transfer the packet by broadcast.

Definition 2 (ignition rule of transition T3)

If tokens exist in place S2 and the discover packet is transferred to the smart mobile phone terminal, the transition T3 ignites. The place S2 will consume a token after igniting, and S4 will add a token; and $P_{ri}e = P_{ri}d$, $1 \leq i \leq 7$.

Definition 3 (ignition rule of transition T4)

If tokens exist in place S4 and the discover packet is correct by CRC inspection, the transition T4 ignites. The place S4 will consume a token after igniting, and S5 will add a token; and $P_{r1}f = 2$, $P_{ri}f = P_{ri}e$, $2 \leq i \leq 3$. Authentication, IP address, port number and CRC check code are respectively expressed as Y_1, Y_2, Y_3, Y_4 ; then, $P_{r4}f = Y_1$, $P_{r5}f = Y_2$, $P_{r6}f = Y_3$, $P_{r7}f = Y_4$. Y_1 is equal to the authentication field corresponding to the module identifier ID in the table 1, Y_2 is equal to IP address that smart mobile phone terminal is using, and Y_3 is equal to the port number that the smart mobile phone terminal is using for realizing the infusion monitoring.

Definition 4 (ignition rule of transition T5)

If tokens exist in place S5, the transition T5 ignites. The place S5 will consume a token after igniting, and S6 will add a token.

Definition 5 (ignition rule of transition T7)

If the discover response packet is transferred to the infusion alarm module and $P_{r1}g = 2$, the transition T7 ignites. The place S6 will consume a token after igniting, and S7 will add a token; $P_{ri}l = P_{ri}g$, $1 \leq i \leq 7$.

Definition 6 (ignition rule of transition T8)

If the discover response packet is correct by CRC inspection, and the authentication information in the discover response packet is the same with the authentication information the infusion alarm module saves, and tokens exist in place S7 and S9, the transition T8 ignites. The place S7 and S9 will consume a token after igniting, and S10 will add a token; $P_{ri}u = P_{ri}l$, $1 \leq i \leq 7$.

Definition 7 (ignition rule of transition T9)

If tokens exist in place S11, the transition T9 will ignite after delaying T seconds. The place S11 will consume a token after igniting, and S12 will add a token; $P_{ri}w = P_{ri}v, 1 \leq i \leq 7$.

Definition 8 (ignition rule of transition T10)

If tokens exist in place S12 and S9, the transition T10 ignites. The place S12 and S9 will consume a token after igniting, and S1 will add a token; $P_{ri}c = P_{ri}m, 1 \leq i \leq 7$.

Alarm and exit communication model

Fig. 4 presents the alarm and exit communication model.

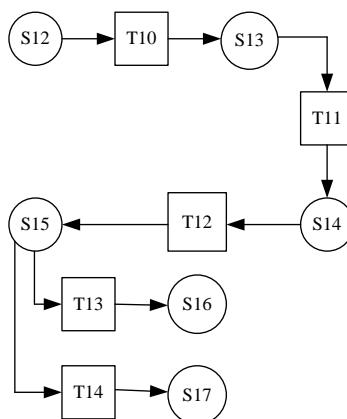


Fig. 4 Alarm and exit communication model

The alarm and exit communication model is used to complement the alarm and exit function. When the infusion alarm module detects that the infusion fluid reaches the warning line, it will notify the smart mobile phone terminal by the alarm and exit communication model, then the smart mobile phone terminal executes the alarm operation. After the patient completes the infusion, the infusion alarm module will exit by the alarm and exit communication model. When the infusion alarm module needs to send alarm packet and exit packet to smart mobile phone terminal, it will request to establish a TCP connection between them. After a connection is built, the infusion alarm module will send alarm packet and exit packet. Because TCP connection can provide reliable communication, the alarm and exit communication model does not need to consider the case of packet loss.

In this model, the place S12 stores the alarm packet or exit packet that the infusion alarm module needs to send; the place S13 stores the alarm packet or exit packet that the channel needs to send; the place S14 stores the alarm response packet or exit response packet that the smart mobile phone terminal needs to send; the place S15 stores the alarm response packet or exit response packet that the infusion alarm module receives; the place S16 and S17 respectively store the alarm response packet and exit response packet that the infusion alarm module receives. Assuming that packet composite colour of token on place S12-S17 are respectively expressed as n, o, p, q, r and s .

Definition 9 (ignition rule of transition T10)

If tokens exist in place S12 and $P_{r1}n = 6$ or $P_{r1}n = 8$, the transition T10 ignites, and the place S12 will consume a token after igniting, and S13 will add a token; and $P_{ri}o = P_{ri}n, 1 \leq i \leq 7$. The infusion alarm module will transfer the packet by TCP connection.

Definition 10 (ignition rule of transition T11)

If tokens exist in place S13, the transition T11 ignites. The place S13 will consume a token after igniting, and S14 will add a token.

Definition 11 (ignition rule of transition T12)

If tokens exist in place S14 and $P_{r_1}n = 7$ or $P_{r_1}n = 9$, the transition T12 ignites, and the place S14 will consume a token after igniting, and S15 will add a token; and $P_{r_i}q = P_{r_i}p$, $1 \leq i \leq 7$.

Definition 12 (ignition rule of transition T13)

If tokens exist in place S14 and $P_{r_1}n = 7$, the transition T13 ignites, and the place S15 will consume a token after igniting, and S16 will add a token; and $P_{r_i}q = P_{r_i}p$, $1 \leq i \leq 7$. After the transition T13 ignites, the infusion alarm module will stop sound and light alarm, TCP connection between the infusion alarm module and smart mobile phone terminal will be removed, and then wait for the nurse to deal with.

Definition 13 (ignition rule of transition T14)

If tokens exist in place S14 and $P_{r_1}n = 9$, the transition T14 ignites, and the place S15 will consume a token after igniting, and S17 will add a token; and $P_{r_i}q = P_{r_i}p$, $1 \leq i \leq 7$. When the transition T14 ignites, the infusion alarm module stops the liquid level detection, clears the IP address and the port number information which is stored in the storage of the infusion alarm module, and TCP connection between the infusion alarm module and smart mobile phone terminal will be removed.

Model simulation

Discover communication model simulation

When needing to use an infusion alarm module to monitor the infusion process, through the key module of infusion alarm module, monitoring signal is sent to the micro controller of infusion alarm module. After micro controller receives the monitoring signal, micro controller readouts the module identifier ID from the storage of infusion alarm module, generates discovery packet. The specific communication process is as follows: setting the initial identification of the place S1, under the initial state, other places have not tokens. The initial state of discover communication model is shown in Fig. 5. The initial identification setting of place S1 is as follows: $M_0(S1) = 1 \langle 1, Z_2, 0, 0, 0, 0, Z_7 \rangle$.

According to the activation conditions and priorities of the transitions in the discover communication model, if the infusion alarm module can receive the discover response packet in T seconds, executing the transitions T1, T3, T4, T5, T7, T8 and T9, the final state of discover communication model is shown in Fig. 6. In final state, $M(S10) = 1 \langle 2, Z_2, 0, Z_4, Z_5, Z_6, Z_7 \rangle$, $M_0(S12) = 1 \langle 1, Z_2, 0, 0, 0, 0, Z_7 \rangle$. The relative reachable graph without packet loss is shown in Fig. 7.

If there is no packet loss, from the transition sequence, we can see the transition T1, T3, T4, T5, T7, T8 and T9 trigger once, finally the marking of S10 is obtained. The simulation results show that the discover communication model based on coloured Petri net is reachable. In the process of simulation, the place S2, S4, S5, S6, S7, S9, S10, S11 have one token at most, so the discover communication model is bounded; all markings can make a transition enable, and there is no deadlock phenomenon. So the discover communication model based on coloured Petri net is active.

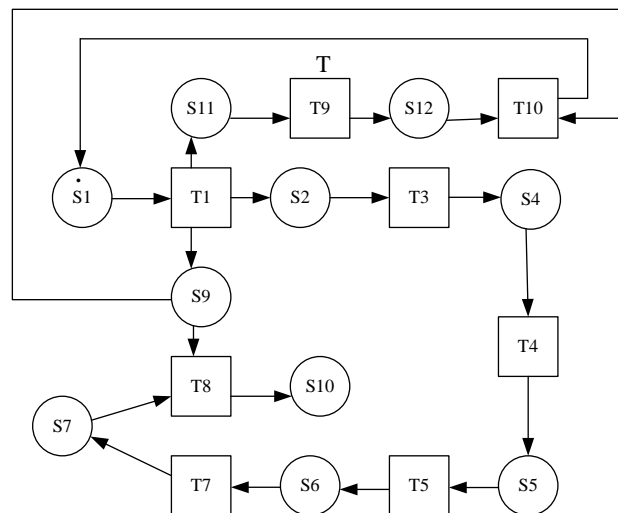


Fig. 5 Initial state of discover communication model

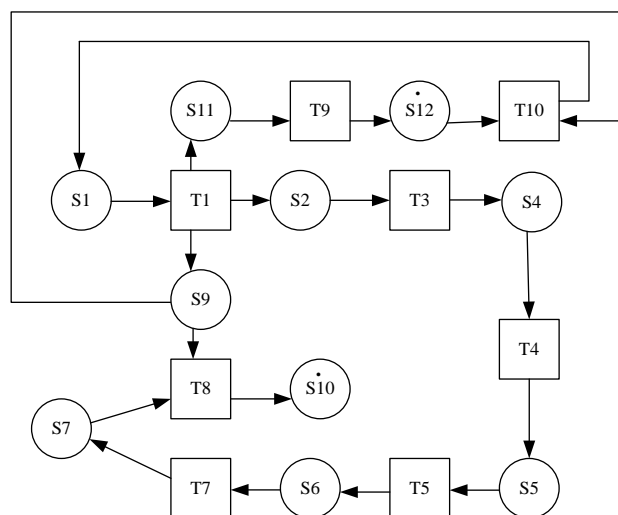


Fig. 6 Final state of discover communication model without the packet loss

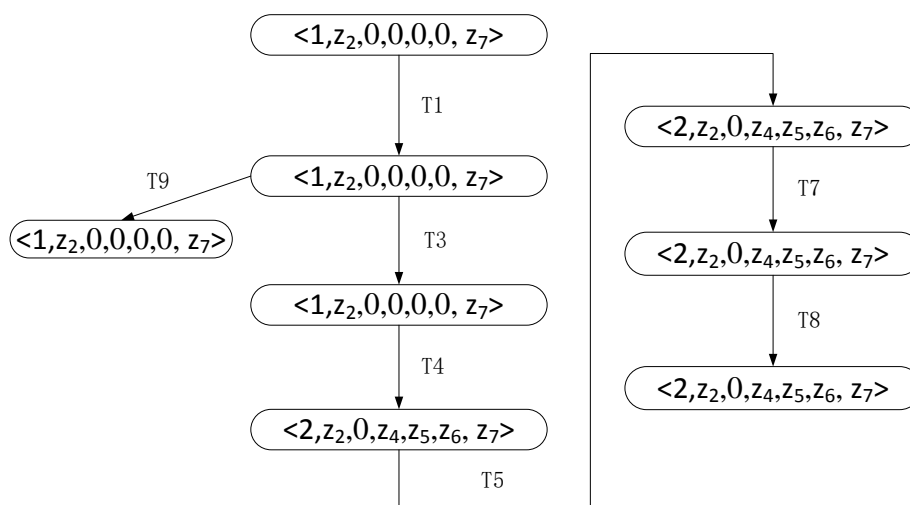


Fig. 7 Reachable graph without packet loss

If the infusion alarm module cannot receive the discover response packet in first T seconds, and there exists packet loss, executing the transitions T1, T3, T4, T5, T9, T10, T1, T3, T4, T5, T7, T8 and T9, the final state of discover communication model is shown in Fig. 8. In final state, $M(S6) = 1 \langle 2, Z_2, 0, Z_4, Z_5, Z_6, Z_7 \rangle$, $M(S10) = 1 \langle 2, Z_2, 0, Z_4, Z_5, Z_6, Z_7 \rangle$. The relative reachable graph with packet loss is shown in Fig. 9.

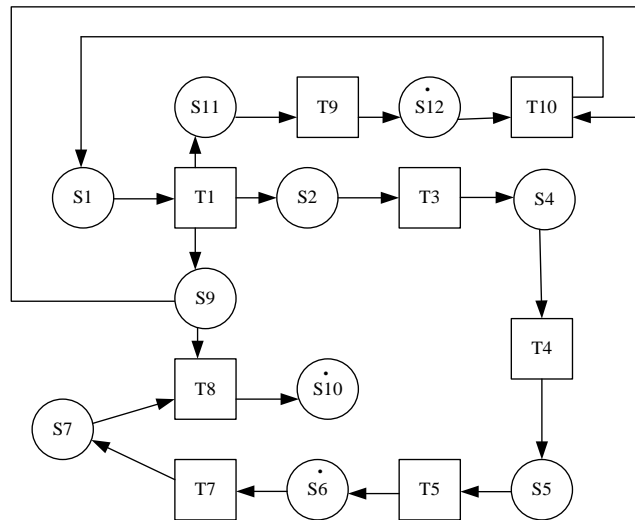


Fig. 8 Final state of discover communication model with the packet loss

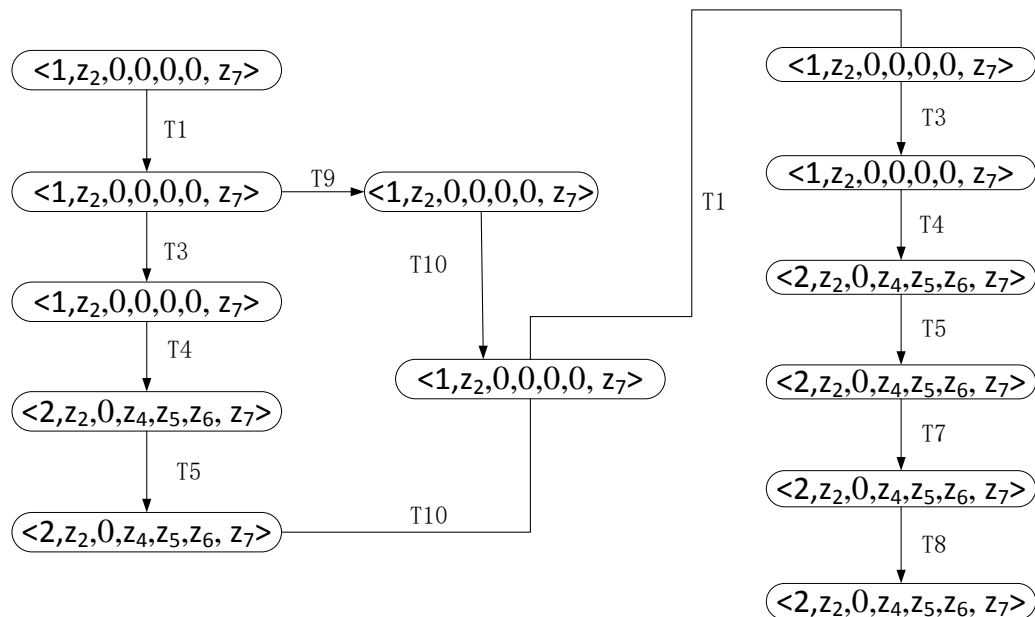


Fig. 9 Reachable graph with packet loss

If there exists packet loss or packet error, from the transition sequence, we can see the transition T1, T3, T4, T5, T9 trigger twice, the transition T7, T8 and T10 trigger once, finally the marking of S10 is obtained. The simulation results show that the discover communication model based on coloured Petri net is reachable. In the process of simulation, the place S2, S4, S5, S6, S7, S9, S10, S11 and S12 have one token at most, so the discover communication model is bounded; all markings can make a transition enable, and there is no deadlock phenomenon. So the discover communication model based on coloured Petri net is active.

The above analysis shows that regardless of whether there is a packet loss, as long as there exist intelligent mobile terminal and corresponding infusion alarm module in the network, S10 is reachable. So the discover communication model can make the infusion alarm module to realize automatically search and identification function of smart mobile phone terminal.

Alarm and exit communication model simulation

After the infusion alarm module receives the discover response packet, it can obtain and save IP address and port number of smart mobile phone terminal. When the infusion alarm module detects that the fluid reach the warning line, through the wireless transceiver module it will establish a TCP connection between the infusion alarm module and selected smart mobile phone terminal. The specific communication process is as follows: setting the initial identification of the place S12, under the initial state, other places have not tokens. The initial state of discover communication model is shown in Fig. 10.

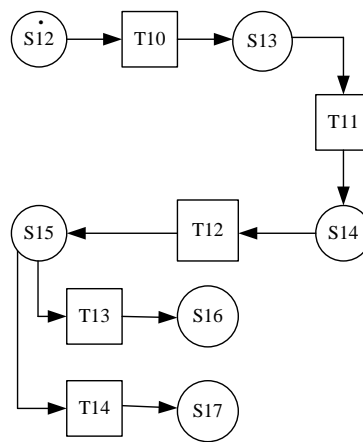


Fig. 10 Initial state of alarm and exit communication model

If the sent packet is an alarm packet, $M_0(S12) = 1 \langle 6, Z_2, 0, 0, 0, 0, Z_7 \rangle$; executing the transitions T10, T11, T12 and T13, the final state of alarm and exit communication model is shown in Fig. 11. In final state, $M(S16) = 1 \langle 7, Z_2, 0, Z_4, Z_5, Z_6, Z_7 \rangle$; when the sent packet is an alarm packet, the relative reachable graph is shown in Fig. 12.

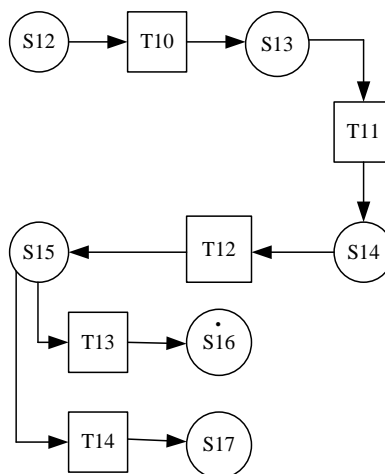


Fig. 11 Final state of alarm and exit communication model when alarming

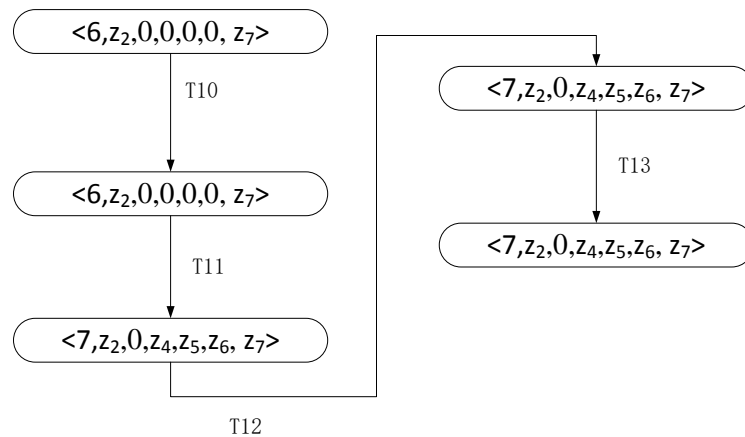


Fig. 12 Reachable graph when the sent packet is an alarm packet

When the sent packet is an alarm packet, from the transition sequence, we can see the transition T10, T11, T12 and T13 trigger once, finally the marking of S16 is obtained. The simulation results show that the alarm and exit communication model based on coloured Petri net is reachable. In the process of simulation, the place S12, S13, S14, S15 and S16 have one token at most, so the alarm and exit communication model is bounded; all markings can make a transition enable, and there is no deadlock phenomenon. So the alarm and exit communication model based on coloured Petri net is active.

If the sent packet is an exit packet, $M_0(S12) = 1\langle 8, Z_2, 0, 0, 0, 0, Z_7 \rangle$; executing the transitions T10, T11, T12 and T14, the final state of alarm and exit communication model is shown in Fig. 13. In final state, $M(S17) = 1\langle 9, Z_2, 0, Z_4, Z_5, Z_6, Z_7 \rangle$; when the sent packet is an exit packet, the relative reachable graph is shown in Fig. 14.

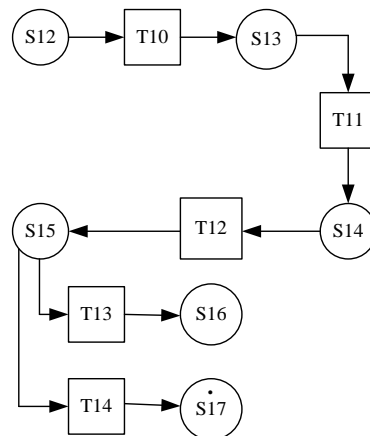


Fig. 13 Final state of alarm and exit communication model when exiting

When the sent packet is an exit packet, from the transition sequence, we can see the transition T10, T11, T12 and T14 trigger once, finally the marking of S17 is obtained. The simulation results show that the alarm and exit communication model based on coloured Petri net is reachable. In the process of simulation, the place S12, S13, S14, S15 and S17 have one token at most, so the alarm and exit communication model is bounded; all markings can make a transition enable, and there is no deadlock phenomenon. So the alarm and exit communication model based on coloured Petri net is active.

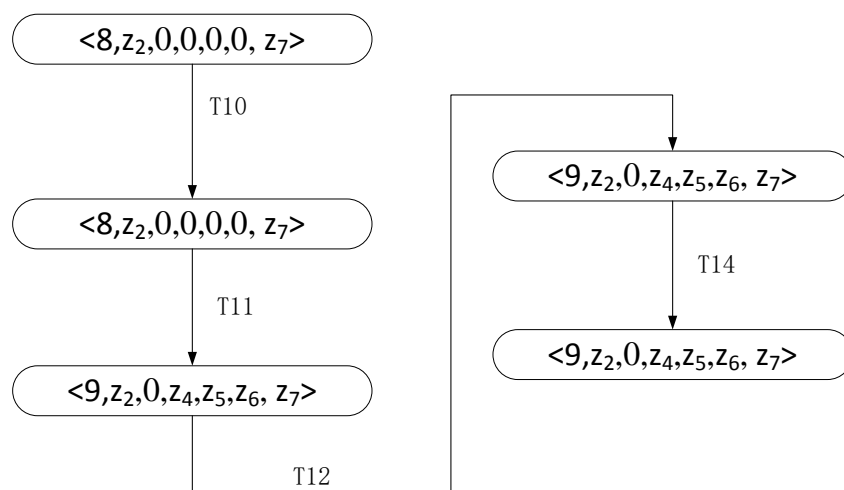


Fig. 14 Reachable graph when the sent packet is an exit packet

The above analysis shows that S16 and S17 are reachable for initial token of S12. When the infusion alarm module detects the infusion alarm, through the alarm and exit communication model, it can be timely notify smart mobile phone terminal for processing. At the same time, after infusion is completed, it can make the infusion alarm module timely exit network.

Conclusion

The infusion monitoring communication model of smart home based on coloured Petri net, which is proposed in this paper, can use smart mobile phone to construct an adaptive infusion monitoring system at home. The model can make infusion alarm module automatically search for smart mobile phone terminals in a WiFi network, complete the search, identification, monitoring and other functions. It will constitute a smart phone infusion monitoring network so that infusion online monitoring could effectively be completed at home without adding additional equipment. The simulation result shows that regardless of whether there is a packet loss, as long as there is a smart mobile phone terminal and the corresponding infusion alarm module in the network, the model can make the infusion alarm module to realize automatic search function of the smart phone mobile terminal and infusion monitoring function, and provide better medical service for the smart home. The infusion monitoring communication model owns characteristics of simplicity, fast inference and wide universality.

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