A VEHICULAR HEALTHCARE SYSTEM USING ANYCAST AND PERVASIVE COMPUTING

One Pervasive Computing Application on Mobile Software and Services

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Abstract: One vehicular healthcare system is proposed to provide secure and stable transmission in wireless environments. Using anycast and pervasive computing technology, the robustness and real-time transmission model is provided for the ambulance to communicate with the target hospital via wireless GPRS transmission in very limited and tolerant data loss. The message reliable transmission method between the ambulance and the hospital with 3 Transmission Devices connecting to 3 GPRS networks is proposed. Each time two out of three TDs are selected to transmit the packet and its duplicate. Using anycast, it doesn't cause the overload condition as with multicast, one MRN selection method is proposed for the router to achieve the load-balancing condition in MRG.

1 INTRODUCTION

The healthcare system is gradually important as the people getting old and resident far away from the hospital and the nursing people. We proposed this paper with the system architecture and the message reliable transmission method are parts of the healthcare system project as depicted in Figure 1.

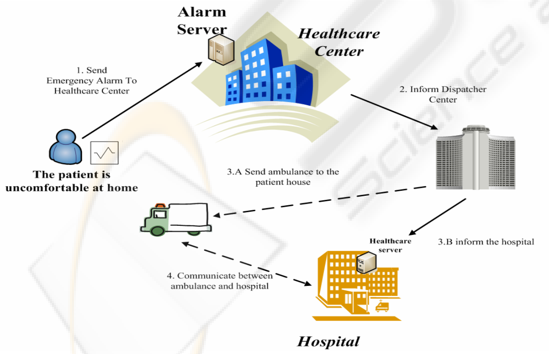

Figure 1: Project view - the healthcare system.

Normally the aged or health-cared person is vital sign monitored by the sensor devices with periodically sending the data to the healthcare center. At the moment of uncomfortable from the monitored person and showing the urgent data to the alarm server, the healthcare center will inform the dispatcher center to send the ambulance to the patient's house and also ask the target hospital to prepare. After the ambulance arrived and the patient is carried into the ambulance, our proposed vehicular healthcare system is started to set up the secure stable communication to the hospital.

The most important feature of healthcare system is the secure and stable data transmission capability. When sufficient information is provided to the doctors and the nursing people, they thus can do the correct judge. But the data loss probability exists, and the hardware cost can not be too huge, therefore we need to find the trade-off point.

The paper describes the vehicular healthcare system providing stable transmission in wireless environments. Using anycast and pervasive computing, one robustness and real-time transmission model is provided for the ambulance to communicate with the hospital via wireless GPRS transmission.

Anycast is defined in RFC3068 (HINDER, DERRING, 1995), and has great difference with multicast and broadcast. When the data is transmitted, via broadcast, each network node can receive the data; via multicast, only these network nodes in that multicast group can have the data; via anycast and underlying routing protocols, only one of network nodes in the anycast group has the data.

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Anycast is very suitable to provide stable services (Dow, Hsuan, Hwang, 2006) (Metz, 2002) (Matsunaga, Ata, Kitamura, Murata, 2005); each network node in the same group, whether far or near to the user, can provide the same service, and the user doesn't need to care where the service nodes are, but can access the service with the group address; especially while one of group network nodes is failed (Jia, Xu, Zhao, 2000), the remaining nodes can still provide the same service via underlying routing protocols.

2 SYSTEM ARCHITECTURE

The system architecture of vehicular healthcare system is shown on Figure 2. Three wireless transmission devices (TDs) are equipped in the ambulance, and each device is respectively connected to GPRS network and also to Internet. The receiving side, the side with the hospital, receives the vital sign data from the ambulance via the network nodes in MRG (Message Relay Group). MRG is one anycast group, the data is transmitted with stateless protocol (such as UDP) and the destination is MRG.

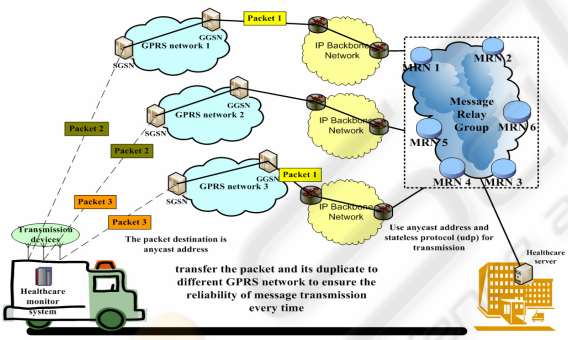

Figure 2: System Architecture of Vehicular Healthcare System.

Through underlying routing protocols (such as OSPF, IGP) and using the anycast address as the destination address, the router can forward the packet to the "proper" MRN (Message Relay Node). The "proper" here means the router can find the met MRN by comparing several parameters, such as the forwarding load in the MRN, the current left buffer size, or the living status, etc. MRN periodically sends the heartbeat messages to update its status to the nearby router. If none of the heartbeat messages is found during several period times, the router will delete the routing information for this MRN in the routing table. Normally the router can forward the packet to several MRNs in the MRG. The action to delete the information in the routing table can avoid the generation of "black hole" and thus reduce the possibility of packet loss.

2.1 System Components

Three system components, healthcare monitor system / MRNs in MRG / healthcare server, are described in this healthcare system. Healthcare monitor system is located in the ambulance. And healthcare server with the mapping MRNs are located in the hospital side.

2.1.1 Healthcare Monitor System

It is located in the ambulance to collect the vital sign data from the patients and transmit the data to the hospital. The system has several vital sign sensors and three TDs. The reason to use three TDs is to prevent the data loss, even if one of the devices is failed. Besides, each time the data and its duplicate will be sent to the hospital respectively through two of three TDs and their mapping GPRS paths. This can reduce the effect of data loss, while the wireless transmitting signal is weak or having other issues that prevent the data from reaching the related GPRS nodes. The duplicated data should be removed in the application layer of receiving side of the hospital. Though sending the data with its duplicate at the same time would waste the transmission bandwidth in the normal condition, it greatly decreases the possibility of data loss.

2.1.2 Message Relay Node

It is abbreviated as MRN and is the node to receive anycast packet, many MRNs exist in the system. Through underlying routing protocols and the anycast address, each time the data in the ambulance can be sent to any and exactly one MRN. This can avoid the waste of the bandwidth, and the data can be securely sent to the running MRN.

Router can be aware of MRN's living status by periodical receiving the heart-beat messages from that MRN. And router relies on the MRN decision parameters, described in the following paragraph, and coordinates with underlying routing protocol (such as OSPF, IGP) to select one MRN and forwards the anycast packet to that MRN.

The MRN decision parameters are,

[MRN_alive]

= 1, means this MRN is alive and it has sent heart-beat message to the router
= 0, means this MRN is not alive
[MRN_load]
= (int) N, the sent packet amount to this MRN (from the router), it is statistical value.
= 0, if MRN_live = 0, this value will be cleared to 0.
[MRN_buffer_usage]
= (int) M, indicates how many packets are queued in this MRN, the packet amount value is sent with heart-beat message from this MRN.

The MRN selection rule is
(MRN_alive=1) AND Min(MRN_load) AND Min(MRN_buffer_usage)

Each MRN is connected to healthcare server in the hospital, and finally healthcare server should handle the data from the selected MRN.

2.1.3 Healthcare Server

It is used to receive the vital sign data from the ambulance. Since stateless protocol is used to transmit the data, call setup procedure is not applied. While the first data packet comes to the server, one session table is automatically built to route the following data packets to the specified line. The session table contains three columns: source address, 3G's IMUI data, and the sequence number of received UDP packet. To have this information in the server, the extra IMUI data should be added to the packet while the ambulance is sending the vital sign data and connects with the application layer of the hospital.

Since each packet and its duplicate are sent via two respective paths, one sequence number field should be added in the payload of UDP. In the receiving side, the packet-duplication-removal procedure should be applied in the application layer. That is, each time the UDP packet (payload) is received and the sequence number should be compared with the one in the session table of the same source address. If the sequence number of the received UDP is greater than the current sequence number in the session table, the UDP packet handling procedure can go on; otherwise, the received packet is spare and should be dropped.

In this paper, we aim at providing reliable and stable message transmission while the ambulance is on the way to the hospital. Therefore it is not the intension to further describe the received data handling in the healthcare server.

2.2 System Behaviours

When the patient at the event place was taken care and moved into the ambulance, the healthcare monitor system starts its operations and transmits the data to the hospital, the data includes the vital sign data (heart-beat rate, blood pressure, etc.) retrieved from the sensors and the monitoring video view of the patient. The vocal communication between the nursing people (in the ambulance) and the hospital uses normal 2G/3G mobile phone system, and is totally separated from the healthcare monitor system.

Each data is divided into several UDP packets for transmission and the destination address is MRG's anycast address. Each UDP packet should insert the IMUI of the healthcare monitor system and the sequence number of this UDP packet. The packets are transmitted through the TDs to the MRNs (of the same anycast address) of the target hospital. In the system, three TDs are equipped in the healthcare monitor system and each time two out of three TDs are selected to transmit the UDP packet and its duplicate, thus to enforce the possibility of successful data transmission. Supposed that the index number of TD is from 0 to 2, and TD_i stands for transmission device i, each time the selected transmission devices are TD_i and $TD_{(i+1) \bmod 3}$,where *i= (Sequence_Number) mod 3.*

The reason for each time having two TDs with two separated paths is to make trade-off between the bandwidth saving and the data loss possibility. When the UDP packet finally arrived at the specified MRN, it would judge to accept that packet by checking the buffer usage of this node. And the packet should be kept in the FIFO buffer, until it is finally transmitted to the healthcare server.

3 ANALYSIS

First, the analysis on the packet loss rate of the system is explained. Second, the hardware cost comparison using between anycast and multicast to build up MRG is described.

3.1 Data Loss Probability and Required Min. MRN Node Number

For easy explanation, Figure 3 is used as the basis of the system architecture for message reliability analysis.

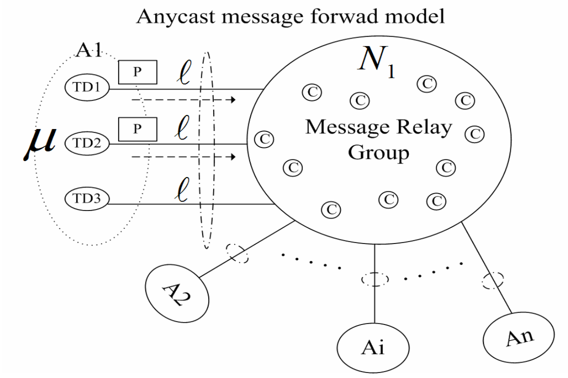

Figure 3: System Architecture for Message Reliability Analysis.

Symbol Definitions:

μ : The summation of traffic load of TD*i* set (%)

Ai: The ambulance i

$|A|$: The number of Ambulance

ℓ : The routing path loss probability

C: The capacity of each Message Relay Node

C_j : The buffer used in Message Relay Node

$R_j := C - C_j$, the remaining buffer space of MRN

P: The packet size

N_1 : The total node number in MRG

Figure 3 shows the anycast message forwarding model. Each time two transmission paths are selected to deliver the packet and its duplicate. Assumed that μ is the total transmission load in three TDs of the specified ambulance Ai. The transmission load is defined as the data transmission probability in one unit time. It is also assumed that the transmission load in each ambulance is the same, and the data loss probability ℓ in each path from TD to MRG has the same amount, but the path breakdown case is not counted in. The parameter ℓ is affected only when the MRN totally fails or when the buffer is full and no new data can be accepted. C is the buffer capacity/amount of the specified MRN. When buffer is fully occupied, the coming packet will be dropped/lost. R_j is the remaining buffer space of the specified MRN. N_1 is the total node number (MRN number) in MRG.

For easy calculation, it is assumed that through anycast routing the data and its duplicate can arrive in MRG, and if either the specified data or its duplicate is failed to arrive, this indicates data loss. From this assumption, the following two rules are defined:

(Rule 1) $\frac{2}{3}\mu \circ \ell$

Rule 1 is the data loss probability in each ambulance with 3 TDs and each time 2 data packets are sent, where ℓ is the routing path loss probability.

(Rule 2) $2|A|\mu P \geq P\left(\sum_{j=1}^{N} R_j\right)$

Rule 2 is the condition when data loss occurs in the whole system. This means when the total sending packet size is great or equal to the total remaining buffer size, the data loss occurs.

Under the condition of Rule 2, that is, $2|A|\mu P - P\left(\sum_{j=1}^{N} R_j\right) \geq 0$, the average routing path loss probability is $\ell = \frac{2|A|\mu P - P\left(\sum_{j=1}^{N} R_j\right)}{N_1 CP}$, if further assumed that the whole MRG with proper underlying routing protocol can achieve the load-balancing condition, that is, $R_1 \cong R_2 \cong \cdots \cong R_N \cong \beta$ for MRNs in MRG. Therefore

(Rule 3) $\ell \cong \frac{2|A|\mu P - PN\beta}{N_1 CP} = \frac{2|A|\mu - N_1\beta}{N_1 C} = \frac{2|A|\mu}{N_1 C} - \frac{\beta}{C}$

Assumed $\frac{\beta}{C} = \sigma$, is the average remaining buffer space ratio (percentage), and $\frac{|A|\mu}{N_1 C} = \kappa_1$ is the average packet amount coming to each MRN. Put these two parameters into Rule 1,

(Rule 4) $\frac{2}{3}\mu \circ \ell \cong \frac{2}{3}\mu \circ [2\kappa_1 - \sigma]$

Rule 4 is the system average packet loss probability, when $2|A|\mu P \geq P\left(\sum_{j=1}^{N} R_j\right)$.

For easy calculation, Rule 4 is based on the assumption that when either the packet or its duplicate is lost, it counts as the data loss. When Rule 4 is adjusted in the real case and divided by the sending packet amount, it has the real packet loss probability:

(Rule 5) $\frac{1}{2} \circ \frac{2}{3}\mu \circ [2\kappa_1 - \sigma] = \frac{1}{3}\mu \circ [2\kappa_1 - \sigma]$

For the real data loss probability, Table 1 is shown to compare with different TD number (how many Transmission devices, 1 to 4) allocated in the ambulance and each time different number of duplicates (0, 1, or 2) sending to MRG with anycast routing mechanism.

Table 1: the real data loss probability with TD number and duplicates.

Anycast	TD=1	TD=2	TD=3	TD=4
One	$\mu\circ[\kappa_1-\sigma]$	$\frac{1}{2}\mu\circ[\kappa_1-\sigma]$	$\frac{1}{3}\mu\circ[\kappa_1-\sigma]$	$\frac{1}{4}\mu\circ[\kappa_1-\sigma]$
Duplicate		$\frac{1}{2}\mu\circ[2\kappa_1-\sigma]$	$\frac{1}{3}\mu\circ[2\kappa_1-\sigma]$	$\frac{1}{4}\mu\circ[2\kappa_1-\sigma]$
Triples			$\frac{1}{3}\mu\circ[3\kappa_1-\sigma]$	$\frac{1}{4}\mu\circ[3\kappa_1-\sigma]$

TD: Transmission Device, $\kappa_1 = \frac{|A|\mu}{N_1 C}$, $\sigma = \frac{\beta}{C}$

Observed from Table 1, when [TD = 2] and [duplicate = 1](Duplicate) the data loss probability is $\frac{1}{2}\mu\circ[2\kappa_1-\sigma]$, but if one TD fails, the data loss probability raises to $\mu\circ[2\kappa_1-\sigma]$; Compared with [TD = 3] and [duplicate = 1](Duplicate), the data loss probability raises from $\frac{1}{3}\mu\circ[2\kappa_1-\sigma]$ to $\frac{1}{2}\mu\circ[2\kappa_1-\sigma]$, when one TD fails; Compared with [TD = 4] and [duplicate = 1], the data loss probability rises from $\frac{1}{4}\mu\circ[2\kappa_1-\sigma]$ to $\frac{1}{3}\mu\circ[2\kappa_1-\sigma]$. Therefore it rises about 50% for [TD = 2], 17% for [TD = 3], and 8% for [TD = 4]. And from per-TD viewpoint, it contributes 25% for [TD =2], 5.6% for [TD = 3], and 2% for [TD = 4]. It is concluded that with [TD = 3] and compared with [TD = 2], one additional TD hardware cost is added, but it greatly reduce the data loss probability. That is, to trade-off between system stability and additional hardware cost, [TD = 3] is the optimal one.

Next, the required minimum MRN node number is depicted.

Message Relay Node Constraints

Let ℓ^C be the expectation value of data loss probability, under TD = 3,

(Rule 6) $\frac{1}{2}\circ\frac{2}{3}\mu\circ\ell = \frac{1}{3}\mu\circ[2\kappa_1-\sigma]\leq \ell^C$

Put $\kappa_1 = \frac{|A|\mu}{N_1 C}$ into Rule 6, then

(Rule 7) $N_1 \geq \frac{2|A|\mu}{C}\circ\frac{\mu}{3\ell^C+\mu\sigma}$

N_1 is the needed MRN node number in MRG.

When the network is full loaded and $R_j = 0$ for each MRN, then $\sigma\to 0$, therefore the ratio of MRN node number vs. |A| (ambulance number) is

(Rule 8) $\frac{N_1}{|A|} \geq \frac{2}{3\ell^C C}$

When Rule 8 is applied in real system configuration and assumed that the data loss probability for patient video view transmission is 10%, $\frac{N_1}{|A|} \geq \frac{20}{3C}$. That is, if MRN node number is greater than $|A|\circ\frac{20}{3C}$, the overall system data loss probability is 10%.

Table 2 shows the required minimum MRN node number list.

Table 2: Required Min. N_1.

Anycast	TD=1	TD=2	TD=3
One	$N_1 \geq \frac{\lvert A\rvert\mu^2}{C(\ell^C+\mu\sigma)}$	$N_1 \geq \frac{\lvert A\rvert\mu^2}{2C(\ell^C+\mu\sigma)}$	$N_1 \geq \frac{\lvert A\rvert\mu^2}{3C(\ell^C+\mu\sigma)}$
Duplicate		$N_1 \geq \frac{\lvert A\rvert\mu^2}{C(\ell^C+\mu\sigma)}$	$N_1 \geq \frac{2\lvert A\rvert\mu}{3C(\ell^C+\mu\sigma)}$
Triples			$N_1 \geq \frac{\lvert A\rvert\mu^2}{C(\ell^C+\mu\sigma)}$

From Table 2, when more TD number is and each time delivery packet number is less than TD number, less N_1 is. In Table 1 and Table 2, with TD = 3 and duplicate = 1(Duplicate) it is the trade-off result to compete with the required minimum MRN node number and the low data loss probability. That's the system design goal to find the trade-off point with the minimum installed hardware cost and the highest transmission stability.

In Table 3, the required minimum MRN node number to build up stable transmission system under network fully loaded condition ($\sigma\to 0$) is depicted.

Table 3: The Required Min. N_1, when $\sigma\to 0$.

Anycast	TD=1	TD=2	TD=3
One	$N_1 \geq \frac{\lvert A\rvert}{C\ell^C}$	$N_1 \geq \frac{\lvert A\rvert}{2C\ell^C}$	$N_1 \geq \frac{\lvert A\rvert}{3C\ell^C}$
Duplicate		$N_1 \geq \frac{\lvert A\rvert}{C\ell^C}$	$N_1 \geq \frac{2\lvert A\rvert}{3C\ell^C}$
Triples			$N_1 \geq \frac{\lvert A\rvert}{C\ell^C}$

3.2 Comparison between Anycast and Multicast

From section 3.1, the combination of [TD = 3] and [duplicate = 1] is the trade-off point. In this section, further comparison using between anycast and multicast under such combination ([TD = 3] and Duplicate) is described.

Based on Rule 1 and Rule 2 of section 3.1 and while multicast routing is used, the Rule 9 and Rule 10 are generated,

(Rule 9) $\frac{1}{N_2} \circ \frac{2}{3}\mu \circ \ell$

(Rule 10) $2N_2|A|\mu P \geq P\left(\sum_{j=1}^{N} R_j\right)$

Compared with N_1 of section 3.1 by using anycast routing algorithm, N_2 is the required minimum MRN node number with multicast routing algorithm. With Rule 9 and Rule 10, $\ell = 2\kappa_2 - \sigma$, where $\kappa_2 = \frac{|A|\mu}{C}$, $\sigma = \frac{\beta}{C}$.

Follow Rule 7 of section 3.1, the same way of calculation is proceeded to get the number of N_2 in Rule 11, $\frac{1}{N_2} \circ \frac{2}{3}\mu \circ [2\kappa_2 - \sigma] \leq \ell^C$

(Rule 11) $N_2 = \frac{6|A|\mu - 3C\sigma}{2\mu\ell^C C}$

Apply Rule 11 when $\sigma \to 0$, gets

(Rule 12) $N_2 = \frac{3|A|}{\ell^C C} = 4.5N_1$

One example with Rule 12, when the average data loss probability is 10%, buffer size = 10 for each MRN, and $\sigma \to 0$, they have $N_1 = 10$ and $N_2 = 45$ ($N_2 = 4.5N_1$). This is because each data is sent to all MRNs with multicast routing algorithm and the buffer of each MRN is soon fully occupied, therefore the network is full of duplicated data and the network usage performance is soon reduced. As the matter of fact, it is the benefit of anycast routing algorithm to secure the data to be forwarded to healthcare server, only if any MRN in MRG can have the data.

4 CONCLUSIONS

The message reliable transmission method between the ambulance and the hospital with the system architecture of 3 TDs is proposed in this paper. Each time two out of three TDs are selected to transmit the UDP packet and its duplicate. Using anycast, it doesn't cause the overload condition as with multicast, the estimated load difference between them is $O(N_2/2)$. The MRN selection method is proposed for the router to achieve the load-balancing condition in MRG.

From the analysis, the combination of [TD = 3] and [duplicate = 1] is the trade-off point between system transmission stability and additional hardware cost. That is, it is the most proper architecture to set up the stable wireless transmission between the ambulance and the hospital. Also if one TD fails under such combination, the data loss probability rises 17%. Besides, the required minimum MRN node number for anycast and multicast is respectively calculated. And the ratio of N_2 (for multicast) and N_1 (for anycast) is 4.5. That is, using anycast and compared with multicast, 4.5 less MRN node number is required to build MRG and the same level of data loss probability is achieved.

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