A Fuzzy Call Admission Control Scheme for Emergency Telecommunications via High Altitude Platforms

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Abstract: High Altitude Platforms (HAPs) are considered as a new generation of wireless communications infrastructure, combining key advantages of both terrestrial and satellite systems. A unique property of HAPs is that they can be deployed quickly over high risk areas in a disaster scenario and provide additional capacity to existing damaged networks. In this situation efficient use of limited spectrum resources would be of great importance. This paper suggested a fuzzy adaptive guard channel assignment technique in a HAP-based cellular system with considering an estimated emergency communications traffic pattern for catastrophic events. Simulation results showed that the proposed fuzzy scheme outperforms the static guard channel assignment and complete sharing techniques in terms of grade of service (GoS) of the network while keeping handoff failures low under time varying traffic load.

Key words: High altitude platforms (HAPs) • Quality of service (QoS) • Call admission control (CAC) • Guard channel • Fuzzy • Handoff

INTRODUCTION

HAPs can be classified as the third layer of communications infrastructure after terrestrial and satellite systems, aims to provide reliable narrowband and broadband wireless services. These platforms are quasi stationary airships or aircrafts operate at an altitude of 17–22 km above the Earth’s surface. A great advantage in the use of HAPs for cellular systems is the possibility of providing emergency coverage over damaged areas in case of disasters, considering the fact that natural or man-made catastrophic events such as hurricanes, earthquakes and acts of war, can cause severe damage to terrestrial infrastructures and even if some communication links survive the effects of the disaster, their capacity cannot respond to the very high demand for services after the event [1], while the HAPs-based systems offer a unique alternative for these situations due to their good coverage to any type of geographical zone and using significantly less communications infrastructure than is required by terrestrial networks [2, 3].

On the other hand, quality of service (QoS) provisioning is always a challenging issue in wireless cellular networks since the availability of spectrum resources and user’s itinerary is not known in advance [4]. Call admission control (CAC) as a fundamental mechanism used for QoS provisioning limits the access to the network, based on availability of resources in order to prevent network congestion and optimize resource utilization. When a new call attempt is rejected this service denial is known as call blocking and its probability is also known as call blocking probability ($P_b$). During the period of conversation, if a mobile user moves out of one cell to another, handoff occurs. A successful handoff requires sufficient amount of available resources to be allocated at target cell; otherwise network has to drop the call before it ends. The forced termination of an uncompleted call is known as call dropping and its probability as call dropping probability ($P_d$). It is difficult to minimize both $P_b$ and $P_d$ at the same time because as each of these two parameters decreases, another one increases accordingly but handoff failures waste valuable wireless resources.
since a data transaction dropped during the process has to be restarted from the beginning [5]. Moreover, from the user’s point of view, forced termination of an on-going call is more annoying than being blocked on a new call attempt. Therefore, it is acceptable to give a higher priority to handoff calls over new calls. One simple and famous technique for prioritizing handoff requests is called guard channel assignment. In this technique a fraction of total available channels in a cell is entirely reserved for handoff calls while the rest of channels are shared among handoff and new calls. Fixed channel assignment techniques usually fail in utilizing the limited channels [6] while, dynamic channel assignment schemes has been shown to provide higher capacity when the traffic load per cell varies [7-9] and also particularly useful when the network traffic load is hard to predict [10, 11].

Related and Previous Works: Many CAC schemes have been suggested for wireless cellular networks so far. A fixed channel assignment strategy with power roll off approximation for overlapping cells is evaluated in [12] for HAPs networks, however, the real traffic model of users is not specified. In [13] an adaptive power control is used for HAP-UMTS based on W-CDMA, in order to improve $P_1$ although the adaptive power control is usually too complex to be applied to real mobility task. Recently, intelligent techniques have been widely used in CAC algorithms. Uncertain measurements such as fuzzy logic offer effective solutions to simplify precise mathematical models and can also be helpful to approximately describe the performance of complex systems [14]. A fuzzy CAC scheme is presented in [15] to provide QoS guarantees in wireless cellular networks, while gives a higher priority to handoff calls over new calls. The performance of suggested scheme is compared with an adaptive channel reservation scheme. Genetic algorithm is also used as a robust technique to increase the performance of dynamic channel allocation in mobile satellite systems [16, 17].

In the previous work [14] an adaptive channel allocation technique was suggested based on fuzzy logic for emergency mobile communications provided by HAPs-based cellular systems. A fuzzy controller was designed to choose the optimum number of guard channels according to network traffic load and some important QoS parameters. In order to model an emergency scenario, higher volume of emergency call arrival rates with shorter mean duration of voice calls was assumed compared with normal situations owing to the fact that the demands for calling emergency answering services (such as 911) generally increases rapidly after occurring a disaster, while the length of conversations gets shorter [18]. In this paper we aim to extend our previous work by simulating a more accurate emergency communications traffic pattern after a catastrophic event. Queueing theory is also included in our simulations, which was not considered before.

System and Traffic Model: In our model, we considered a HAP-based cellular network with limited and equal number of channels (denoted by $C$) in each cell. A fraction of total number of channels in a cell (denoted by $C_g$) is exclusively reserved for handoff requests, while the remaining $(C-C_g)$ channels are shared among both handoff calls and new calls. The new calls and handoff calls arrival rates are considered to follow Poisson process with rates $\lambda_h$ and $\lambda_n$ respectively and the call holding time is exponentially distributed with mean $1/\mu$. A new call attempt will be accepted into the network if total number of busy channels in a cell is less than $C-C_g$; otherwise, it will be blocked. On the other hand, a handoff request will be admitted if there is at least one idle channel at the destination cell. We proposed a queuing model similar to the one used in [15, 19] for wireless cellular networks in which for a cell capacity of $C$, each available channel is considered as a server and the system state space is a finite set $E = \{0,1,2,...,C\}$. The state transition diagram is shown in Figure 1.

Let be the steady-state probability that the system is in state $j$, then the balance equation of the system can be obtained like that [19]:

$$
\begin{align*}
P_0 &= \frac{\left(\lambda_n + \lambda_h\right) k!\mu^k}{k!\mu^k} + \sum_{k=C-C_g+1}^{C} \frac{\left(\lambda_n + \lambda_h\right)^{C-C_g} \lambda_n^{k-C} \lambda_h^k}{k!\mu^k}, \\
P_j &= \begin{cases} 
\left(\lambda_n + \lambda_h\right) j!\mu^j P_0, & 1 \leq j \leq C - C_g \\
\left(\lambda_n + \lambda_h\right)^{C-C_g} \lambda_n^{j-C} \lambda_h^j \mu^j P_0, & C - C_g + 1 \leq j \leq C
\end{cases}
\end{align*}
$$

A new call attempt will be blocked if the number of busy channels in a cell is more than $C-C_g$. Therefore:

$$
P_b = \sum_{j=C-C_g}^{C} P_j
$$

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A handoff request will be rejected if the number of busy channels is equal to. Hence:

\[ P_d = P_c \]  \hspace{2cm} (4)

The GoS which is a critical criterion is also defined as a weighted linear function of \( P_n \) and \( P_r \) [13].

\[ \text{GoS} = \omega_n \frac{\lambda_n}{\lambda_n + \lambda_h} P_n + \omega_h \frac{\lambda_h}{\lambda_n + \lambda_h} P_d, \] \hspace{2cm} (5)

Where and are weighting factors of new calls and handoff calls. is selected to be greater than, because handoff failure is less desirable to users than being blocking on a new call attempt.

In order to estimate call volumes and traffic patterns for an emergency response HAP, we used data which was collected from various resources and combined in [18]. Emergency call trends were estimated from a 2006 conflict call pattern and then it was normalized and applied to a worst-case emergency scenario which was an improvised explosive scenario. Using the population estimate from the improvised scenario and emergency call patterns, in Erlangs,

\[ \text{Fig. 1: State-transition diagram} \]

\[ \text{Fig. 2: Estimated worst-case emergency calls pattern} \]

\[ \text{Fig. 3: Block diagram of FLC} \]

Figure 2 was derived. In the Figure 2 it is evident that the erlang contributions from emergency calls are very low. The reason is that although the emergency call volumes are very high, the mean duration of calls are very short [18].

**Fuzzy Channel Assignment Scheme**

**Fuzzy Logic Controller (FLC) Structure:** FLC is the main part of proposed fuzzy scheme which is made of: Fuzzifier, Inference engine, Fuzzy Rule Base and Defuzzifier. The Fuzzifier transforms crisp values of input parameters into fuzzy linguistic terms by means of membership functions. The Inference Engine performs a logical inference according to Fuzzy Rule Base and the Defuzzifier is used to convert the output into crisp values. The structure of FLC is shown in Fig. 3. The input linguistic parameters of proposed FLC are \( P_d \) and \( C_r \). The output linguistic parameter is set as tuning number of guard channels (denoted by \( \Delta C \)). The design of the FLC is based on Mamdani fuzzy model.

**Membership Functions:** Fuzzy membership function relates an element \( x \) of the universe to a fuzzy set and usually takes a value between 0 and 1. As membership functions, triangular and trapezoidal functions are chosen because of simplicity and suitability for real-time operations [20]. The term sets of input and output membership functions are defined as follows:

\[ T(P_d) = \{ \text{Very low; low; Middle; high; Very high} \} \]
\[ T(C_r) = \{ \text{Zero; Very Small; Small; Middle; Big} \} \]
\[ T(\Delta C) = \{ \text{Negative Very Big; Negative Big; Negative Middle; Negative Small; Zero; Positive Small; Positive Middle; Positive Big; Positive Very Big} \} \]

They are shown in Figure 4, Figure 5 and Figure 6.
Fig. 4: Membership functions for call dropping probability

Fig. 5: Membership functions for number of the guard channels

Fig. 6: Membership functions for tuning number of the guard channels
**Fuzzy Rule Base:** The Fuzzy Rule Base forms a set of rules with dimensions of $|T(P)| \times |T(C)|$, where $|T(x)|$ is the number of terms in $T(x)$. The control rules are shown in Table 1 and have the following form: IF “conditions” THEN “control action”. As an illustration, if the $P$ is Very Low and the $C$ is Small, then it activates the third rule and tunes to $\Delta C$. The fuzzified output parameter will be converted to a crisp value using centroid algorithm (this process refers to defuzzification). Then, its value is added to the last number of guard channels and rounded off for the exact Figure.

**RESULTS**

In this section, simulation parameters and numerical results are presented. In order to fairly evaluate the performance of proposed fuzzy scheme two other famous channel allocation techniques are also simulated in this paper and then the performance of all methods is compared with each other in terms of some important QoS criteria. The first scheme is static guard channel assignment in which number of reserved channels for handoff requests remain constant during the CAC process and the second one is complete sharing scheme. It shares all available channels in each cell between handoff calls and new calls without considering any priority for handoff calls over new calls.

<table>
<thead>
<tr>
<th>Rule number</th>
<th>IF call dropping Probability</th>
<th>AND number of guard channels</th>
<th>THEN tuning number of guard channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Very Low</td>
<td>Zero</td>
<td>Zero</td>
</tr>
<tr>
<td>R2</td>
<td>Very Low</td>
<td>Very small</td>
<td>Negative Small</td>
</tr>
<tr>
<td>R3</td>
<td>Very Low</td>
<td>Small</td>
<td>Negative Middle</td>
</tr>
<tr>
<td>R4</td>
<td>Very Low</td>
<td>Middle</td>
<td>Negative Big</td>
</tr>
<tr>
<td>R5</td>
<td>Very Low</td>
<td>Big</td>
<td>Negative Very Big</td>
</tr>
<tr>
<td>R6</td>
<td>Low</td>
<td>Zero</td>
<td>Positive Small</td>
</tr>
<tr>
<td>R7</td>
<td>Low</td>
<td>Very Small</td>
<td>Zero</td>
</tr>
<tr>
<td>R8</td>
<td>Low</td>
<td>Small</td>
<td>Negative Small</td>
</tr>
<tr>
<td>R9</td>
<td>Low</td>
<td>Middle</td>
<td>Negative Middle</td>
</tr>
<tr>
<td>R10</td>
<td>Low</td>
<td>Big</td>
<td>Negative Big</td>
</tr>
<tr>
<td>R11</td>
<td>Middle</td>
<td>Zero</td>
<td>Positive Middle</td>
</tr>
<tr>
<td>R12</td>
<td>Middle</td>
<td>Very Small</td>
<td>Positive Small</td>
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<tr>
<td>R13</td>
<td>Middle</td>
<td>Small</td>
<td>Zero</td>
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<tr>
<td>R14</td>
<td>Middle</td>
<td>Middls</td>
<td>Negative Small</td>
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<tr>
<td>R15</td>
<td>Middle</td>
<td>Big</td>
<td>Negative Middle</td>
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<tr>
<td>R16</td>
<td>High</td>
<td>Zero</td>
<td>Positive Big</td>
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<tr>
<td>R17</td>
<td>High</td>
<td>Very Small</td>
<td>Positive Middle</td>
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<tr>
<td>R18</td>
<td>High</td>
<td>Small</td>
<td>Positive Small</td>
</tr>
<tr>
<td>R19</td>
<td>High</td>
<td>Middles</td>
<td>Zero</td>
</tr>
<tr>
<td>R20</td>
<td>High</td>
<td>Big</td>
<td>Negative Small</td>
</tr>
<tr>
<td>R21</td>
<td>Very High</td>
<td>Zero</td>
<td>Positive Very Big</td>
</tr>
<tr>
<td>R22</td>
<td>Very High</td>
<td>Very Small</td>
<td>Positive Big</td>
</tr>
<tr>
<td>R23</td>
<td>Very High</td>
<td>Small</td>
<td>Positive Middles</td>
</tr>
<tr>
<td>R24</td>
<td>Very High</td>
<td>Middle</td>
<td>Positive Small</td>
</tr>
<tr>
<td>R25</td>
<td>Very High</td>
<td>Big</td>
<td>Zero</td>
</tr>
</tbody>
</table>

**Table 1 Fuzzy Rule Base**

Fig. 7: Call dropping probability

**Simulation Parameters:** It is supposed that each cell in the HAP-based system consists of $= 30$ channels. In the complete sharing scheme, the algorithm shares all 30 channels among handoff calls and new calls. In the static guard channel assignment the algorithm reserves 4 channels, exclusively for handoff process. The $C$ varies from 0 to 4 in proposed fuzzy scheme. Mean duration of emergency voice calls is set to be $1/\mu = 30$ seconds [18]. According to Figure 2 the offered traffic load varies in a range of about 12–28 erlangs after the event. Hence, emergency call arrival rates () can be obtained from erlang formula:

$$E = \frac{\lambda}{\mu}$$

Where, $\lambda = \lambda_s + \lambda_n$. Therefore, varies from 24 to 56 calls per minute. We assumed that handoff calls arrival rate is related to new calls arrival rate by. The weighting factors of handoff calls and new calls are also selected to be $= 5$ and $= 1$ respectively.

**RESULTS AND DISCUSSION**

The performance measures which are used to show the effectiveness of the fuzzy method are: $P_a$, $P_s$, and GoS. Figure 7 plots $P_a$ of each strategy about emergency calls pattern (presented in Figure 2). The values of $P_a$ in complete sharing scheme is higher than two other schemes. The reason is that, it reserves no channel for handoff requests. Hence, it cannot keep the handoff failures low while, the $P_a$ of static guard channel scheme
The GoS of all schemes is also shown in Figure 9. In day 1 after the event when the demands for emergency services are very high the handoff failures in complete sharing scheme are far higher than two other schemes. Thus, it has worst values of GoS. When emergency call volumes reduces in the following days the static guard channel scheme wastes valuable resources by reserving maximum number of guard channels. Hence, the GoS graph of static guard channel is higher than two others. But it is noticeable that the GoS of proposed fuzzy scheme is lower than other methods all the time. It indicates that when the network traffic load changes after the event, the FLC is able to adjust dynamically the optimum number of reserved channels in order to make more efficient use of resources.

CONCLUSIONS

In this paper an intelligent CAC scheme, based on fuzzy logic is proposed for emergency mobile communications in a HAP-based cellular network. In order not to waste valuable spectrum resources a fuzzy logic controller is designed which is able to dynamically adjust optimum number of guard channels. The performance of suggested fuzzy scheme is compared with static guard channel scheme and complete sharing scheme in terms of some important QoS criteria. The results showed that the fuzzy scheme is able to keep the forced termination probability low and achieve a better GoS.

REFERENCES


