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A Simulation Study of the Handoff Algorithms Based on Fuzzy Decision Making

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Abstract

In the cellular mobile communications, as decreasing the cell radius to increse the reuse factor of frequencies, the handoff requests are increasing so that the efficient handoff decision making becomes a crucial problem. In this simulation study, we evaluate a set of handoff algorithms based on fuzzy-multicriteria decision making. These algorithms uses the parameters including the received signal strength intensity, the bit error rate and the distance between a mobile station and a base station. We compare the fuzzy algorithms in terms of call block ratio and handoff request ratio and call force ratio, and show the applicability of those algorithms in the cellular mobile communication systems.

I. Introduction

The cellular system in mobile communications is one of the efficient techniques for economic utilization of frequency resources[1][2]. To increase the reuse factor of frequencies, the radius of a cell becomes smaller and smaller. As decreasing the cell radius, however, the handoff requests are incresing, and the efficient handoff decision making becomes a crucial problem in the system. In this simulation study, we evaluate a set of handoff algorithms basd on multicriteria decision making.

In general, the handoff decision in digital cellular systems is based on a set of parameters measured from a MS(Mobile Station) and a BS(Base Station) such as the distance between MS and BS, the RSSI(Recieved Signal Strength Intensity), BER(Bit Error Rate) and the traffic amounts[3]. However, those measurements are incorrect and insufficient to make handoff decision. To overcome the insufficiency of the single measuremt, a handoff decision should use several parameters simultaneously and eventually be based on the multicriteria decision making.

Conventional algorithms are based on the binary decision with some hysterisis on the values of parameters. For example[4],

Rule 1 : If ($R_i > R^*$ and $R_i - R_j > \Delta_R$) and ($F_i < F^*$ and $F_j - F_i > \Delta_F$), then handoff occurs from cell C_i to cell C_j.

In Rule 1, $R_i(F_i)$ and $R_j(F_j)$ represent the distances (RSSI) of a MS from its current BS(C_i) and its one of neighboring BSs(C_j), respectively. Also, $\Delta_R(\Delta_F)$ implies the hysterisis to surpress the frequent handoff requests and R^* (F^*) are the lower(upper) bounds of hanoff request.

Our approach is based on the multicriteria decision making using fuzzy set aggregation functions. We calculate the assorted memberships of a MS to all adjacent BSs including current BS, and find a BS that has the largest membership value to decide a target cell.

Similar algorithm has been reported by Munoz Rodrigez and Cattermole[4], in which the truth values of several propositions are aggregated to decide a target cell among neighboring BSs. Also, our study is motivated by Krishnapuram and Lee's aggregation networks[5]. They proposed that several aggregation operators can be used as activation functions in artificial neural networks, and the parameters involved in the operator can be automatically determined through training with prototypical data sets. In this paper, we do not train to obtain the optimal operators, but our work may be extended to such direction.

To evaluate the performance of the handoff algorithms, we assumed 21 BSs, and used 96 channels with 3 different channel assignment strategies. To make comparision of the performances, we selected three performance measures and handoff boundary. As a result of simulation, the algorithm is efficient to prevent unnecessary handoffs in the cell boundaries.

II. Handoff Algorithm Based on Fuzzy Decision Making

Our algorithm for simulation study is similar to the one proposed by Munoz Rodrigez and Cattermole. Their algorithm is shown in Algorithm I and may be represented as Rule 2, since the algebraic sum operator in Step 2 is an union operator and the product operator in Step 3 is an intersection operator:

Rule 2 : If ($R_j < R^*$ or $R_j < R_o$) and ($F_j > F^*$ or $F_j > F_o$) and ($B_j < B^*$ or $B_j < B_o$), then handoff occurs from cell C_o to cell C_j,

where R^*, F^* *and* B^* are predefined thresholds of distance between MS and BS, RSSI, and BER. Note that Algorithm I produces only discrete values of memberships as an assorted truth value of the propositions. Also, note that Step 2 and Step 3 in Algorithm I can be replaced by follows:

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Step 2′ : For each adjacent BS and current BS, and for each decision criterion, find the membership value according to the defined membership function.
Step 3′ : For each adjacent BS and current BS, aggregate the memberships from the criteria using an aggregation operator.

In the modified steps, the memberships of a MS to each neighboring BSs including the current BS are directly evaluated according to the measurements of the parameters and the separate memberships are aggregated to obtain an assorted degree of memberships of a MS to each BS. In this paper, Algorithm I with the modified steps will be called Algorithm I*.

In Algorithm I, Step 1 is prepared to waive the handoff decision when a MS is within the distance R_o^*. Also, TH in Step 4 is provided to surpress the number of handoffs, and to make the algorthim be flexible according to the selection of the threshold value: the smaller value of TH produces larger number of handoffs and the quality of a channel after handoff may not be desirable.

Algorithm I

```
Step 1 : If $R_o > R_o^*$, go to Step 2.
         Otherwise, handoff procedure is not initiated
Step 2 : Find membership values with respect to each
         parameter for all adjacent cell $C_j$ using
            $\mu_R(R_j) = \mu_{R^*}(R_j)+\mu_{R_o}(R_j)-\mu_{R^*}(R_j)\cdot\mu_{R_o}(R_j)$,
            $\mu_F(F_j) = \mu_{F^*}(F_j)+\mu_{F_o}(F_j)-\mu_{F^*}(F_j)\cdot\mu_{F_o}(F_j)$,
         and
            $\mu_B(B_j) = \mu_{B^*}(B_j)+\mu_{B_o}(B_j)-\mu_{B^*}(B_j)\cdot\mu_{B_o}(B_j)$,
         where
            $\mu_{R^*}(R_j)=\begin{cases}1 & R_j<R^* \\ 0 & otherwise\end{cases}$,
            $\mu_{R_o}(R_j)=\begin{cases}0.5 & R_j<R_o \\ 0 & otherwise\end{cases}$,
            $\mu_{F^*}(F_j)=\begin{cases}1 & F_j<F_j^* \\ 0 & otherwise\end{cases}$,
            $\mu_{F_o}(F_j)=\begin{cases}0.5 & F_o<F_j \\ 0 & otherwise\end{cases}$,
            $\mu_{B^*}(B_j)=\begin{cases}1 & B_j<B_j^* \\ 0 & otherwise\end{cases}$,
         and
            $\mu_{B_o}(B_j)=\begin{cases}0.5 & B_j<B_o \\ 0 & otherwise\end{cases}$.
Step 3 : Find the membership of a MS to $C_j$ using
            $\mu_j = \mu_R(R_j)\cdot\mu_F(F_j)\cdot\mu_B(B_j)$.
Step 4 : Handoff from $C_o$ to $C_k$
         if $\mu_k = \max(\mu_j)$, and , $\mu_k \ge TH$,
         otherwise no handoff occurs.
```

Algorithm I* is so generalized that we may have a lot of variations depending on the selected decision parameters, corresponding membership functions, and aggregation operators.

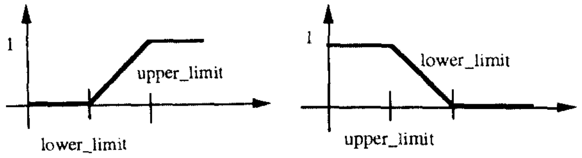
The membership functions that we use are shown in Fig. 1. (The membership value of BER is calculated by taking logarithm of B from eq. (8).) Note that the membership functions provide continuous values rather than discrete values in Algorithm I. For aggregation of membership values, one may choose many operators according to the attitude involved in the aggregation[5] or one may use the aggregation network to find optimal operators as proposed by Krishnapuram and Lee. In this simulation study we select a product operator as

$$\mu_j=\mu_R(R_j)\cdot\mu_F(F_j)\cdot\mu_B(B_j), \tag{1}$$

and a weighted averaging operator as

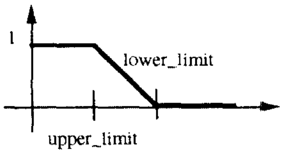
$$\mu_j=\mu_R(R_j)\cdot W_R+\mu_F(F_j)\cdot W_F+\mu_B(B_j)\cdot W_B, \tag{2}$$

where $W_R+W_F+W_B=1$. In eq. (1) and eq. (2), $\mu_R(R_j)$, $\mu_F(F_j)$ and $\mu_B(B_j)$ are membership value of a MS to C_j with respect to distance, RSSI and BER, respectively. The reason why we take such operators is that they are more or less simple to calculate.



upper_limit = 7.5
lower_limit = 5.5
(a) RSSI

upper_limit = 90
lower_limit = 120
(b) Distance



lower_limit = -5.5
upper_limit = -7.5
(c) BER

Fig. 1. The trapezoidal membership functions

III. Simulations

A. Assumptions

To do the simulation, we assumed 21 BSs spatially allocated as shown in Fig. 2, and used 96 linearly ordered channels with 3 different channel assignment strategies: one FCA(Fixed Channel Assignment) and two DCAs(Dynamic Channel Assignment)[7]. We consider 3 types of interferences, which are the co-channel interference

$$| f_{il} - f_{jk} | \ge 1 \quad , \text{if } d(i,j) \le 3, \tag{3}$$

the adjacent channel interference

$$| f_{il} - f_{jk} | \ge 2 \quad , \text{if } d(i,j) = 1, \tag{4}$$

and the co-site interference

$$| f_{il} - f_{ik} | \ge 5 \quad , \text{if } d(i,i) = 0, \tag{5}$$

where f_{il} and f_{jk} are channel numbers in cell C_i and C_j and $d(i,j)$ represents the shortest distance between the centers of C_i and C_j normalized with 1 when C_i and C_j are adjacent.

For FCA, we preallocated 7 or 8 channels to each BS which do not violate the interference conditions. We used two different strategies for DCA: the one is called SIMPLE in which a channel is assigned to a call or handoff request whenever it does not violate the interference conditions, the other is called MAXAVAIL in which a channel selected, which maximizes the system-wide availability of channel capacity among the channels which do not violate the conditions[8].

In the simulation, RSSI was calculated by

$$F = \frac{K}{1+\exp(-(A-2)/2)} \qquad (6)$$

and

$$A = \frac{K_1}{d^2} + K_2 \cdot N(0,1), \qquad (7)$$

where d is the distance between a MS and a BS. In eq. (6) and eq. (7), the constants K, K_1 and K_2 were 10, 30000 and 0.7, respectively. Also, the BER was generated by

$$B = (0.05+0.25(U-0.5)) \cdot \tanh(\frac{1}{0.02 \cdot F}-15.25), \quad (8)$$

where U is a uniform random number in [0,1]. The rationale behind eq. (7) and eq. (8), RSSI should decrease as increasing the distance d and BER should be correlated with RSSI.

The other variables for simulations are summarized with their ranges in Table 1[7]. The probabilities of directional changes were 0.84, 0.07, 0.07 and 0.02 for no direction-change, right-turn, left-turn and U-turn, respectively. The number of call requests in each cell was homogeneous or nonhomegeneous. In nonhomogeneous case, we assumed that the number of call requests in the cells C_7, C_8, C_9, C_{15} and C_{16} at the center of the cell system are approximately twice of that in the other cells.

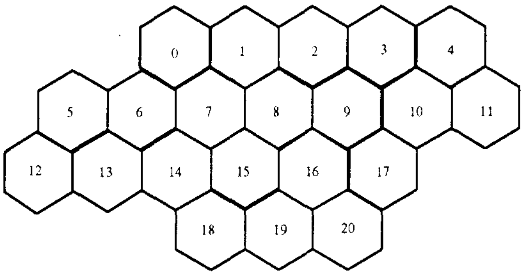


Fig. 2. Cell System Configuration

Table 1. The Summary of Variables and Ranges

variables	contents
Radius of a Cell	1 mile
Call Duration	truncate gaussian of 30~270 second
Speed of MS	truncate gaussian of -60~60 mile/hr
Speed Change	N(0,10) mile/hr for 10 sec.
Moving Directions	0/45/90/135 degrees with uniform distribution
Direction Changes	No Change, left-turn, right-turn, U-turn
cycle time	10 seconds
# of subscribers	1000
# of call requests	homogeneous and nonhomogeneous

B. Overall Procedures

The outline of the simulation program is summarized in Algorithm II. In the program the amount of call requests are controlled by thresholding a uniformly distributed random number. There are three statuses in a MS including Hang_Up, New_Call_Attempt and Call_In_Progress. For a given traffic model, an amount of call requests, a channel assignment method and a handoff strategy, we repeat 1000 times for all 1000 MSs and take statistics.

We considered 4 different handoff strategies, which were

i) the one based only RSSI with histerisis as Rule 1,
ii) the one based on Alogorithm I,
iii) the other two based on Algorithm I* with a product operator in eq. (1) and a weighted averaging operators in eq. (2).

Algorithm II

```
Input Traffic Model, Channel Assignment Method and Handoff Algorithm;
Initialize all BS;
Initialize all MS's Status with INIT;
Repeat 1000 times {
  For each MS {
    If MS's Status = INIT, then
      Set the Status INIT or New_Call_Attempt;
    Switch (MS's Status) {
      Hang_Up:
        Clear channel;
        MS's Status = INIT;
      New_Call_Attemp:
        Search available channels;
        If no channel exists, then Set MS's Status = INIT;
        Else the Status = Call_In_Progress;
      Call_In_Progress:
        Make Handoff Decision based on Handoff Algorithms;
        If target BS is not equal current BS, then {
          Search available channel in target BS;
          If no channel exits, then Set MS's Status = INIT;
          Else {
            Assign new channel;
            Clear current channel;
          }
        }
        Else no handoff occurs;
    }
  }
}
Calculate statistics;
```

C. Performance Measures

To make comparision of the performances, we selected three performance measures, including CBR, HRR, and CFR[9] defined as follows;

$$CBR(Call\ Block\ Ratio) = \frac{number\ of\ blocked\ calls}{number\ of\ requested\ calls}$$

$$HRR(Handoff\ Request\ Ratio) = \frac{number\ of\ handoff\ requests}{number\ of\ assigned\ calls}$$

and

$$CFR(Call\ Force\ Ratio) = \frac{number\ of\ forced\ calls}{number\ of\ assigned\ calls}.$$

The CBR becomes larger when the number of calls increases, because we restricted the number of channels in the system. Also, the CBR much more depends on the channel assignment policy than the handoff strategy. The HRR is depends on the handoff strategy; the better strategy produces the smaller HRR. The CFR is the ratio of forced calls without hang-up. Therefore the smaller value of CFR is desirable and CFR depends on both handoff and channel assignment strategy.

Also the better handoff algorithm should produce exact handoff requests at the predefined cell boundaries.

D. Results

Our simulation results for homogeneous number of call requests are shown in Fig. 3 thru Fig. 6. (To calculate the statistics we considered the boundary effects of the cell system.) As we expected, the CBR depended on channel assignment strategies and increases with increasing the amounts of call requests. Also, the more the assignment strategy is sophisticated like MAXAVAIL, the better performances were resulted as shown in Fig. 3. In the figures, the traffic amount(abscissa) reprsents the number of calls for a minute in each cell.

We ploted the handoff boundaries in Fig. 4, and adjusted the constants associated with each handoff methods (e.g. histerisis, and various thresholds) in oder that the handoff boundaries were approximately aligned with the cell boundaries.

As in Fig. 5, HRRs were almost constants over varying the number of call requests independent of channel assignment methods. Also, one can find that the smaller HRRs were produced when Algorithm I* with eq. (1) and eq. (2) are used. One of the reason is that the handoff boundaries are indented into the adjacent cells to reduce the unnecessary handoff requests due to MSs wandering about the border of two cells. Also, the CFRs of Algorithm I* with eq. (1) and eq. (2) were greatly decreased as shown in Fig. 6. We believe Algorthm I would produce the smaller HRR and CFR if the handoff boundary is enlarged. (Note the handoff boundary of Algorithm I is smaller than those of Algorithm I* in Fig. 4.) In the case of nonhomogeneous number of call requests in each BS, the overall performances were degraded but the similar results were obtained as in the homogeneous case.

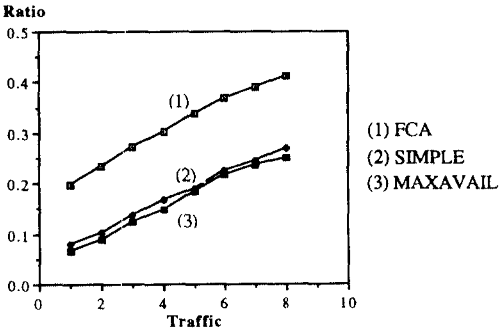
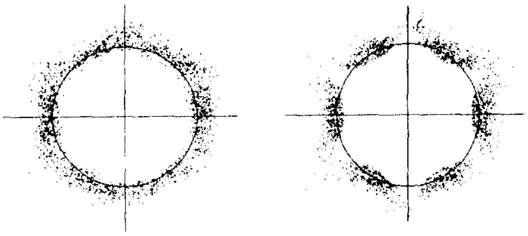
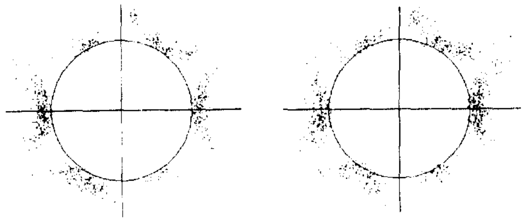


Fig. 3 CBRs according to Channel Assignment Methods (Handoff Strategy was Algorithm I)



(a) Based only on RSSI (b) Algorithm I



(c) Algorithm I* with eq. (1)(left) and with eq. (2)(right)

Fig. 4 Handoff Boundary

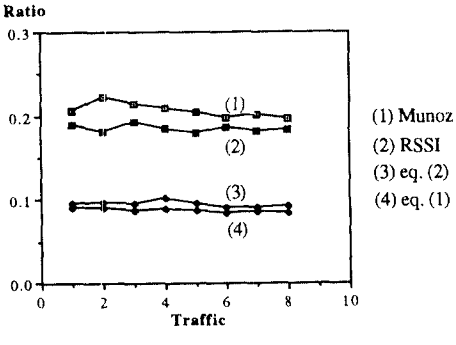


Fig. 5 HRR According to Handoff Methods in case of MAXAVAIL Channel Assignment

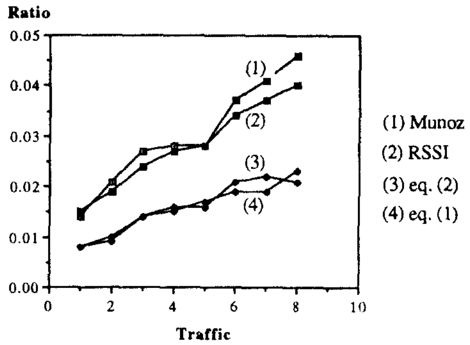


Fig. 6 CFR According to Handoff Methods in case of SIMPLE Channel Assignment

IV. Conlusion

In the cellular mobile communications, as decreasing the cell radius to increase the reuse factor of frequencies, the handoff requests are incresing so that the efficient handoff decision making becomes a crucial problem. In this simulation study, we evaluate a set of handoff algorithms based on fuzzy-multicriteria decision making. Those algorithms uses the parameters including the RSSI, the BER and the distance between a MS and a BS. We compare the performances in terms of CBR, HRR, CFR and handoff boundaries. As the results of simulation, the fuzzy algoritms are efficient to reduce HRR and CFR by preventing unnecessary handoffs in the cell boundaries. Also, we pointed out that the aggregation operators can be automatically determined with the same method as in the aggregation networks proposed by Krishnapuram and Lee.

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