CAC Algorithm Based on Fuzzy Logic

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***Abstract* - Quality of Service (QoS) represent one of major parameters that describe mobile wireless communication systems. Thanks growing popularity of mobile communication in last years, there is an increasing expansion of connection admission control schemes (CAC) that plays important role in QoS delivering in terms of connection blocking probability, connection dropping probability, data loss rate and signal quality.**

With expansion of services provided by the mobile networks growing the requirements to QoS and together growing requirements to CAC schemes. Therefore, still more sophisticated CAC schemes are required to guarantee the QoS. This paper contains short introduction into division of connection admission control schemes and presents threshold oriented CAC scheme with fuzzy logic used for adaptation of the threshold value.

Keywords - Call admission control, fuzzy logic, cellular networks, mobile networks, handoff connection, drop probability.

I. CONNECTION ADMISSION CONTROL

In mobile cellular networks are connections, in term to the certain network cell, divided into two basic classes:

- new connections are connections that arise within this certain network cell
- handoff connections, which are the connections that incurred in another network cell, but they move into the range of this certain network cell (and are take-over by this cell).

Incoming new and handoff connections are accepted or denied to the network by connection admission control scheme (CAC). Decision (accept/deny) is based on predefined criterions and on the network loading conditions. This decision has sensible influence on Quality of Service (QoS) parameters, what makes from CAC an essential tool to guarantee various QoS parameters.

In general holds, that dropping of active connection is more annoying for the end user like blocking of new connection. A priorization of handoff connections before new connections is required. This prirorization can be based on various QoS parameters described in next section.

A. QoS Parameters in CAC

Signal Quality – wireless networks have (in comparison to wired networks) lower capacity limits, with growing load (and number of connections) of the network decrease signal quality for the end users. To avoid of this effect, CAC accept new and handoff connections only in case, if it can guarantee a minimal required value of signal quality to all active connections in network cell including the incoming connection. If the signal quality after admission of incoming connection should decrease, the connection is blocked (handoff connection is dropped). Suitable criterion for decision in this CAC schemes is the number of connections in cell, transmitted power, or signal to interference ratio (SIR).

Connection Blocking/Dropping Probability – once connection is admitted by the network it should be closed only by end user. Dropping of active connection due to insufficient resources is more ineligible in comparison to blocking of new incoming connection. Objective of CAC in this case is to minimize value of the handoff failure probability (P_{hf}) and together to minimize the new connection blocking probability (P_b). As criterion for connection admission can be total number of active connections in network cell, available resources of the cell or estimated value of P_{hf}.

Packet-Level Parameters – in wireless networks with limited bandwidth can high network load cause unacceptable packet delays or delay jitter (decreased network throughput). CAC can avoid this state by blocking of incoming connections that can cause network overload. In this case can be used like admission criterion the count of active connections in network cell, resource availability or estimation of the QoS parameters.

Transmission Rate – guarantee of minimal transfer rate by CAC schemes has been examined in wired networks. In cellular wireless networks is the problem similar, even if more complicated by limited and unstable bandwidth or by user mobility. Similar like CAC for guarantee of packet-level parameters admission criterion can be count of active connections in network cell or resource availability.

For detailed research a CAC algorithm with guard band policy based on connection dropping/blocking probability QoS parameter described in following section was choose.

B. Guard Band Policy

The guard band policy is used by CAC schemes for guarantee connection dropping/blocking probability. In an effort to minimize handoff failure probability (P_{hf}) in some schemes is higher priority given to handoff connections and lower priority to new connections.

CAC scheme based on the guard band policy hold some number of network cell channels reserved for handoff connections only and the rest of the channels are shared by both handoff and new connections. Size of the guard band is given by a threshold value. More channels in guard band (lower value of threshold) leads to lower P_{hf}, side effect of this is higher value of new connection blocking probability (P_b) and vice-versa (higher threshold value causes higher P_{hf} and lower P_b). The goal of this technique is to set the threshold value so that both P_{hf} and P_b are correct controlled (minimized).

Values of P_{hf} and P_b are variable in term to network conditions. Even if is the value of threshold for guard band set correctly, with changing network conditions (load, number of active connections) value of blocking and dropping probability alternate and default threshold value can cause unacceptable variance of P_{hf} and/or P_b.

Dynamic guard band policy was proposed in order to guarantee minimal blocking and dropping probability for each traffic parameters of network cell. Size of guard band (threshold value) is during operation of network cell adapted depending on network cell conditions (load, traffic parameters etc.) so, that minimal value and variance of P_{hf} and P_b is reached. This approach, with suitable strategy for set of threshold value overcomes in many cases the drawbacks of guard band policy with fixed threshold (guard band size).

One from many possible strategies for dynamic adoption of guard band size (threshold value) is implementation of fuzzy logic that control right allocation of guard band size according to some traffic parameters and/or network cell conditions (resource availability).

II. FUZZY LOGIC

Main feature of fuzzy logic is the ability to map input space to output space. Fuzzy logic overcomes the mathematical complexity of many problems, it works with fuzzy terms, fuzzy sets, fuzzy operations and it makes decisions based on fuzzy rules (*if-then* rules). Fuzzy inference system (basic block scheme is depicted in Fig.1) performs four basic steps:

- fuzzyfication
- inference
- composition
- defuzzyfication

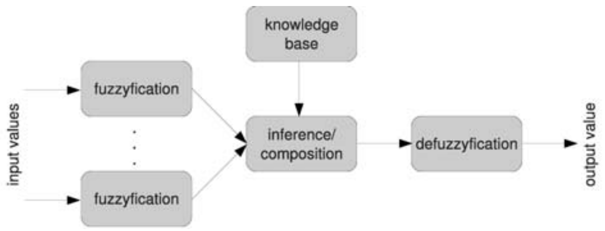

Fig.1. Fuzzy inference system

The essential step in design of fuzzy system is to define fuzzy variables and fuzzy rules. Each fuzzy variable has membership function (in most cases has the membership function trapezoidal or triangular shape) which transform, in the fuzzyfication step, crisp (input) value into degree of membership (value between 0 – 1,

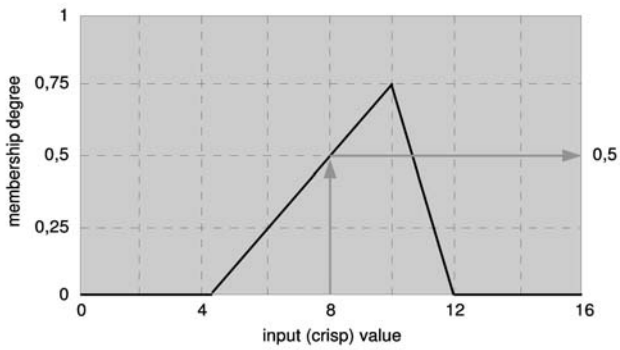

Fig.2).

Fig.2. Triangular membership function

In step of inference are to all inputs applied fuzzy operators based on fuzzy rules (defined in the rule base). All rules have form of if-then conditions:

if x is A then y is B

if x is A and y is B then z is C

Fuzzy operators in fuzzy logic are based on logical operators AND, OR, NOT (Fig.3). Operator AND is in fuzzy system represented by function MIN (minimum), operator OR is represented by function MAX (maximum) and operator NOT x is represented by function $(1 - x)$.

In step of composition is over all outputs of fuzzy rules next fuzzy operator applied. Possible operators in this step are MAX (maximum), PROBOR (probabilistic or) and SUM (simply the sum of each rule output set).

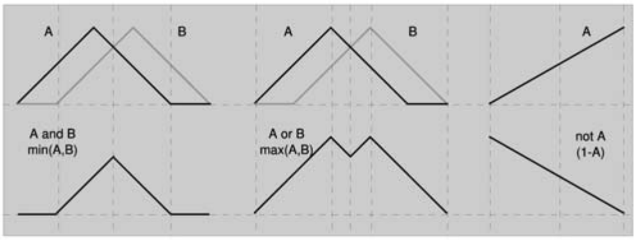

Fig.3. Fuzzy operators applied to inputs A, B

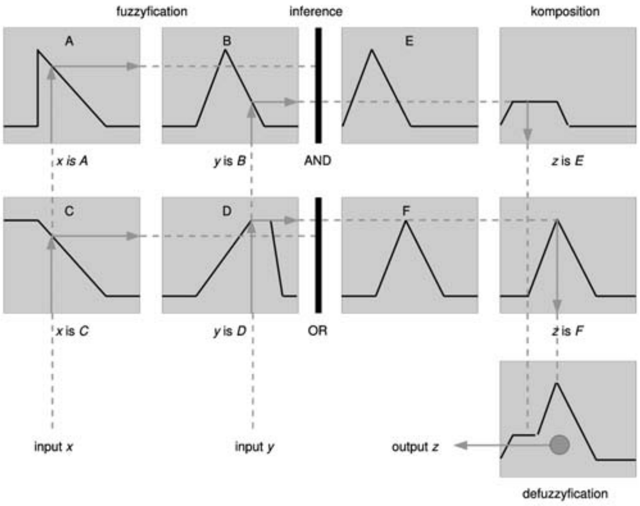

Fig.4. Fuzzy inference diagram

After composition follow step of defuzzyfication which is in principle reverse fuzzyfication. Input for the defuzzyfication process is a fuzzy set and output is a crisp value. Most popular defuzzification method is the centroid calculation, which returns the center of the area under the curve (additional methods are for example bisector, middle of maximum, largest of maximum, smallest of maximum etc.). Fuzzy inference diagram (depicted in Fig.4) show sequence of all steps in fuzzy inference system with two inputs (*x, y*), one output (*z*), two fuzzy rules, six fuzzy variables (A, B, C, D, E, F), MAX operator in composition and centroid defuzzyfication method.

III. FUZZY LOGIC AND CALL ADMISSION CONTROL SCHEME

Thanks main features of fuzzy logic (see Sec.2) it is a suitable tool to increase power of CAC scheme. Ground for this implementation is connection admission control scheme for controlling of connection blocking/dropping probability with guard band policy. Modification of the basic scheme is implementation of movable threshold (variable guard band size, Fig.5). Threshold value increase or decrease by the current conditions in network cell (available resources of the cell, number of incoming handoff connections to cell).

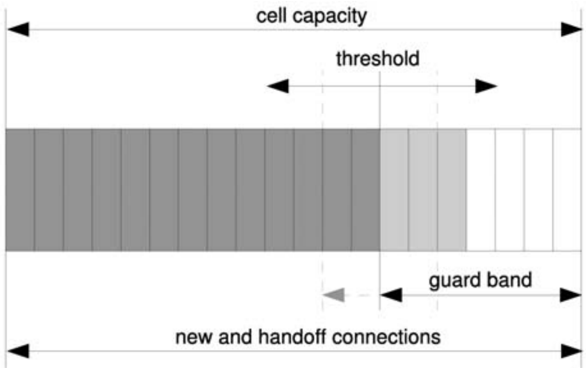

Fig.5. Guard band policy in CAC scheme with movable threshold (variable guard band size)

Value of threshold is updated after each change in cell traffic or cell resource availability (primary after each change of active connections number in network cell, secondary after arrival of any handoff connection). New threshold value is based on output of fuzzy logic subsystem (FLS in Fig.6), which determines the percentage change of threshold value in regard to old threshold value.

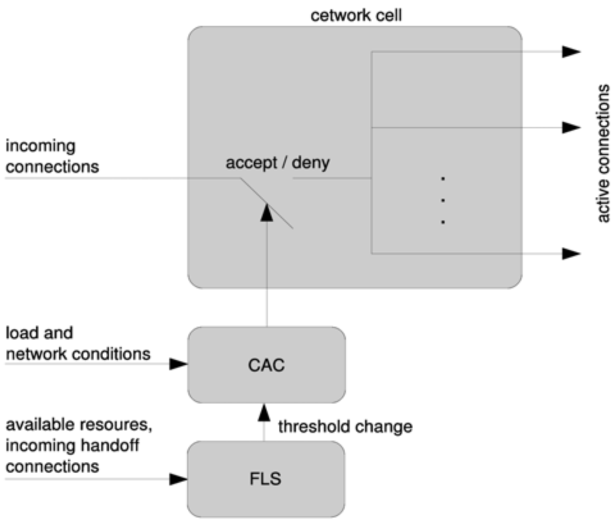

Fig.6. Implementation of fuzzy logic and CAC scheme in connection admission process of network cell

A. Fuzzy Logic Subsystem

The main parameter of CAC with guard band policy is the threshold value that defines the size of guard band. Fuzzy logic subsystem (FLS) in the scheme is responsible for computing of the threshold value, this value is forwarded from FLS to CAC. Mamdani type fuzzy inference system is used for this purpose.

Input Variables

Available Cell Resources (C_A) – percentage of free slots from total number of cell slots, in cell with one class connections computed as:

$$C_A = \frac{L - n * b}{L} \tag{1}$$

where:

L – total number of slots in cell

n – number of active connections in cell

b – number of slots required by one connection

In system with connections of multiple classes is value of available cell resources input computed as:

$$C_A = \frac{(L - (n_1 * b_1 + n_2 * b_2 + ... + n_m * b_m))}{L} \tag{2}$$

where:

n_m – number of active connections for x-th class

b_m – number of slots required by x-th class

m – number of connections classes in cell

Available cell resources input variable is in fuzzy logic subsystem described by six triangular membership functions listed in Tab.1.

TABLE 1. Break points of membership function for C_A input variable

Name	Break 1	Break 2	Break 3
VeryLow	0	0	0.2
Low	0	0.2	0.4
MediumLow	0.2	0.4	0.6
MediumHigh	0.4	0.6	0.8
High	0.6	0.8	1
VeryHigh	0.8	1	1

Arrived Handoff Connections (H_A) – number of handoff connections that arrived to the network cell between current and last update of threshold value. In FLS is defined constraint to maximal 20 incoming handoff connections between two updates of threshold.

The H_A input variable is in fuzzy logic subsystem described by six triangular membership functions and one trapezoidal membership functions listed in Tab.2.

Both input variables are computed before each update of threshold value. *Available cell resources* is computed in preprocessing step, value 0 means that no free slots are in the network cell, value 1 means that the cell has no active connections (all slots of the cell are free). Variable *arrived handoff connections* include all handoff connections, accepted and dropped, which comes to the network cell.

TABLE 2. Break points of membership function for H_A input variable

Name	Break 1	Break 2	Break 3	Break 4
VeryLow	0	0	2	-
Low	0.5	2	3.5	-
MediumLow	2	3.5	5	-
Middle	3.5	5	6.5	-
MediumHigh	5	6.5	8	-
High	6.5	8	9.5	-
VeryHigh	8	9.5	20	20

Output variable

Proposed fuzzy logic subsystem in this scheme has one output variable named *Change*. Value of *Change* is moving within the range of interval <-1; 1> and defines the percentage variation of threshold. The finally value of new threshold is computed as:

$$T_N = T + Change * T \tag{3}$$

where:

T_N – new threshold value

T – current threshold value

Change - FLS output value

Output variable Change is in FLS described by seven triangular membership functions listed in Tab.3. Value of output variable is forwarded directly into CAC where is the value of new threshold finally computed and applied.

TABLE 3. Break points of membership function for Change output variable

Name	Break 1	Break 2	Break 3
DecreaseHigh	-1	-0.9	-0.6
DecreaseMedium	-0.9	-0.6	-0.3
DecreaseLow	-0.6	-0.3	0
NoChange	-0.3	0	0.3
IncreaseLow	0	0.3	0.6
IncreaseMedium	0.3	0.6	0.9
IncreaseHigh	0.6	0.9	1

Fuzzy rules

Rule base in fuzzy logic subsystem contains 42 fuzzy rules (examples of rules are listed in Tab.4). Rules were generated as all possible combinations from all values of input variables (6 values of C_A input and 7 values of H_A input). All rules have weight of 1 and connection between input variables in each rule is fuzzy operation MIN (logical operator AND).

TABLE 4. Examples of fuzzy rules implemented in rule base of the FLS

C_A	Conne-ction	H_A	Change
Very High	and	VeryHIgh	NoChange
High	and	VeryLow	IncreaseMedium
High	and	Low	IncreaseMedium
High	and	MediumLow	IncreaseLow

As inference in FLS is used fuzzy operation MIN, as composition is used fuzzy operation MAX and finally centroid calculation is used as defuzzyfication method.

B. Simulation and Results

A mobile network cell with constant number of total slots and connections of one class was simulated in Matlab environment (signal quality fluctuation was in simulations not considered). Simulation traffic with Poisson probability distribution of incoming connection and connection duration was generated.

Common parameters used in simulations:

- operation duration $T = 1200s$
- number of total cell channels $L = 25$
- fixed threshold value $T_{HR} \in <15;25>$
- average length of new connection $T_N=75s$
- average length of handoff connection $T_H=90s$
- average arrival time of new connection $\lambda_N=0.085$ *connections/s*
- average arrival time of handoff connection $\lambda_H=0.075$ *connections/s*

Threshold value defines number of cannels in network cell shared for both handoff and new connection, size of guard band is computed as $L - T_{HR}$.

IV. RESULTS AND FUTURE WORK

Several simulations with different cell and connection parameters were realized on simulated mobile network cell in Matlab environment.

Results of simulations on network cell showed, that CAC scheme with threshold adapted with fuzzy logic subsystem is able (in comparison to CAC scheme with fixed threshold value) to decrease number of blocked new connections by preservation of handoff connection dropping probability.

In some cases dropping probability can soft increase, what is caused by higher network cell utilization. Usage of CAC scheme with fuzzy threshold decrease number of dropped handoff connections, at the same time in many cases is increased number of blocked new connections (this effect is caused by fact that new and handoff connections share the same cell resources).

TABLE 5. Comparison of blocked/dropped connections count for CAC with fixed and fuzzy threshold

Threshold	Cell utilization (fixed) [%]	Cell utilization (fuzzy) [%]	Diff-erence [%]	Blocked new (fixed)	Blocked new (fuzzy)	Diffe-rence [%]	Dropped handoff (fixed)	Dropped handoff (fuzzy)	Diffe-rence [%]
25	71	67	-4	179	611	241	172	118	-31
24	71	66	-5	258	530	105	161	130	-19
23	72	67	-5	301	511	70	172	159	-8
22	66	62	-4	281	463	65	120	111	-8
21	69	67	-2	341	540	48	119	115	-3
20	68	65	-3	421	518	23	133	132	-1
19	66	67	1	400	482	17	125	129	3
18	68	67	-1	507	521	3	137	144	5
17	65	66	1	504	485	-4	115	118	3
16	65	66	1	541	530	-2	152	154	1
15	68	68	0	618	606	-2	139	141	1
average			-1.9			51.2			-5.2

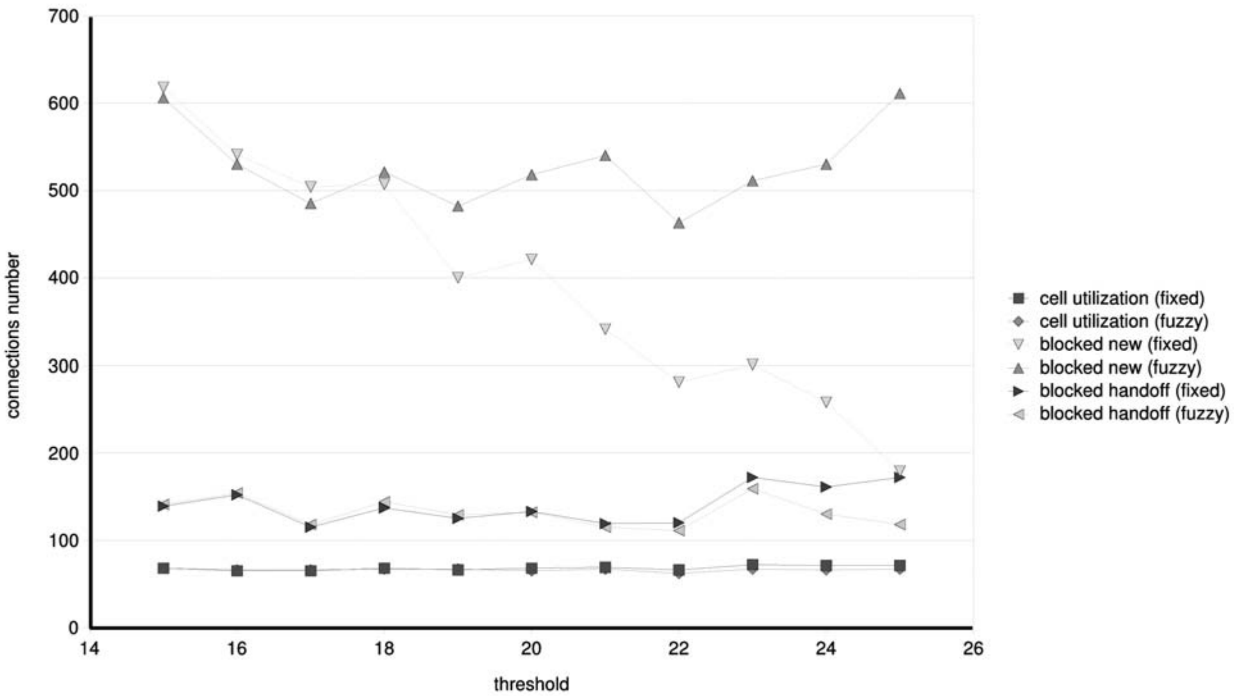

Fig.7. Simulation of mobile network cell traffic with one class connection, CAC scheme with fixed threshold value

All simulations together demonstrate, that threshold adapted by fuzzy logic in connection admission control schemes with guard band policy, has a positive influence on the network cell resources utilization. However drawback of threshold adaptation in this way is the inertia which rise in fuzzy logic, where the threshold value is based on past traffic parameters. This can cause, in some cases, less resource reservation as needed for incoming handoff connections (and following higher dropping probability).

Objective of future work is to remove the drawback of this implementation, for example a prediction system for forecasting of incoming handoff connections can be implemented and threshold value will be adapted with considering of this prediction.

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