Chapter 5

Numerical Results

This chapter uses the simulation experiments to investigate the performance of MECR procedure. We first introduce the discrete event-based simulation for MECR procedure we propose in chapter 3. Then, we use this simulation to validate the analytical model that we propose in chapter 4. Finally, we show the performance of MECR procedure which is investigated by the output measures in terms of $E[N]$, $E[C_u]$ and $E[C_{ru}]$.

5.1 Simulation Model

In this section,we develop a C++ discrete-event simulation to test the performance of MECR procedure. For this research, each data point on the plots shown in this chapter is average of $1,000,000$ samples. We simulate five kinds of event, RANDOM_CHECK, ARRIVAL, CCR_INITIAL, CCR_TERMINATE and CCR_ValidityTimer. The simulation flow chart is shown in Figure 5.1 and the notation used in the simulation flow-chart explained in table 5.1.

When simulation is started, environmental parameters (i.e., λ) and MECR procedure parameters (i.e., θ, T and $c_{\mathtt{mtc}}$) are loaded into the simulation model. The simulation sets initial value and starts to generate the first ARRIVAL event according to MTC record arrival rate λ. Then, the simulation inserts them into the event list [Figure 5.1(A.1)]. Our simulation carries out the next event from the event list and checks

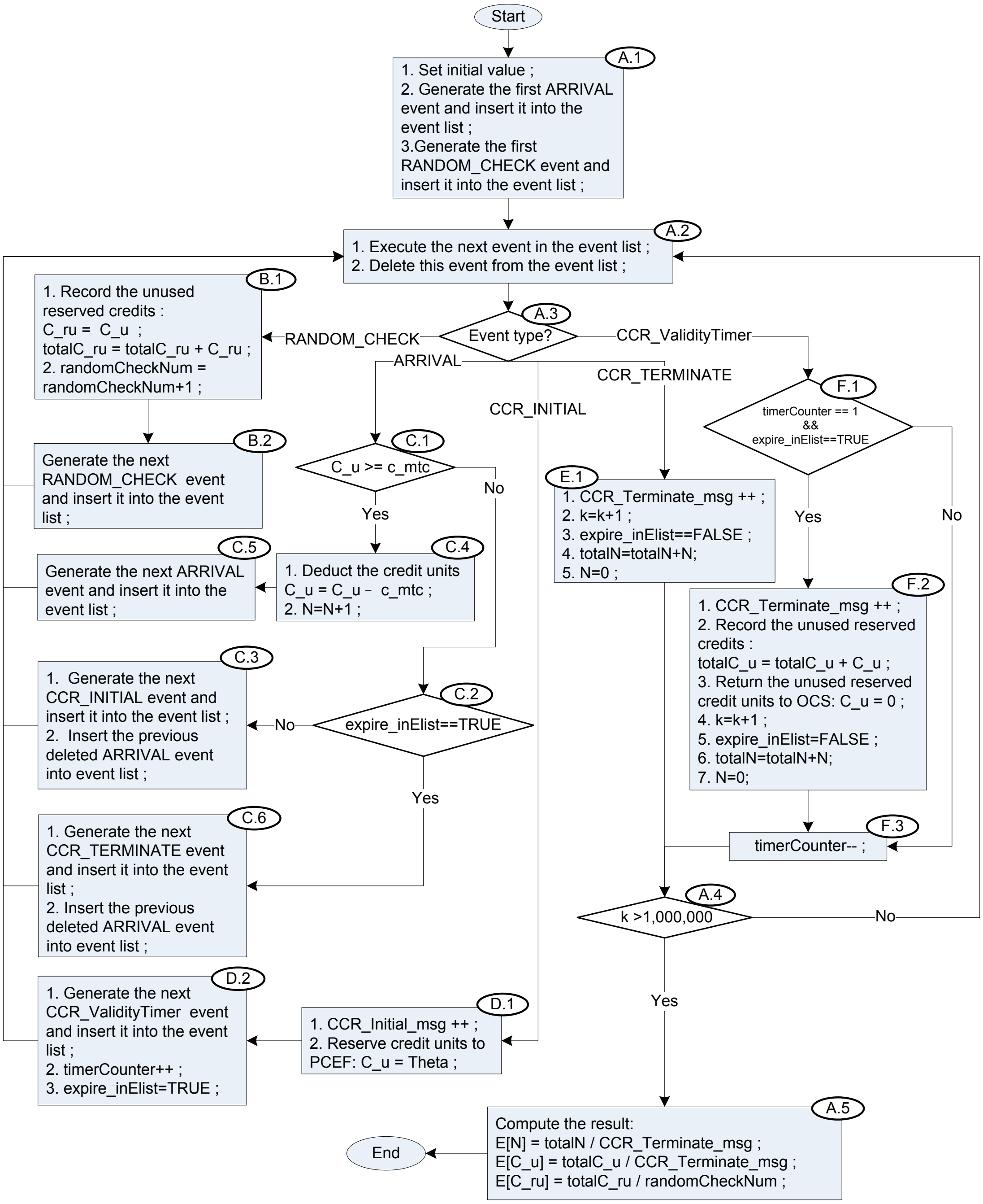


Figure 5.1: The simulation process flow-chart of PCEF Credit Maintenance Cycle.

Table 5.1: The notations of PCEF Credit Maintenance Cycle flow-chart.

Input Parameter	
Theta	Reserved credit units at every reserve unit operation.
T	Validity time period.
c_mtc	Credit units cost per MTC record. In this thesis, each MTC record cost one credit unit.
Event	
ARRIVAL	To handle a new arrive MTC record.
CCR_INITIAL	To handle reserve unit operation event.
CCR_TERMINATE	To handle the credit consumed event.
CCR_ValidityTimer	To handle the validity time expiries event.
RANDOM_CHECK	To handle the observer checks unused reserved credit.
About Credits Parameter	
C_u	Unused reserved credit units that return to OCS at each debit unit operation.
totalC_u	Total unused reserved credits.
C_ru	Unused reserved credit units which generated by RANDOM_CHECK events.
totalC_ru	Total unused reserved credit units which generated by RANDOM_CHECK events.
Other parameter	
N	ARRIVAL event counter.
totalN	Total number of ARRIVAL event.
randomCheckNum	Total number of RANDOM_CHECK event.
CCR_Initial_msg	Total number of CCR(INITIAL-REQUEST) message.
CCR_Terminate_msg	Total number of CCR(TERMINATE-REQUEST) message.
expire_inElist	Whether TIMER_EXPIRY event in event list or not.
timerCounter	Total number of CCR_ValidityTimer event in event list.
Output parameter	
$E[N]$	The expected number of ARRIVAL event (i.e. MTC record) in a CDR.
$E[C_u]$	The expected number of unused reserved credit units return to the OCS at each MECR procedure.
$E[C_{ru}]$	The expected number of unused reserved credit units observed by a random observer.

the event type [Figure 5.1(A.2) and (A.3)]. If the event type is RANDOM_CHECK event, our simulation will carry out this event to check the unused reserved credit units in PCEF and update totalC_ru. Then, it generates the next RANDOM_CHECK event and inserts it into the event list [Figure 5.1(B.1) and (B.2)]. Otherwise, our simulation executes the event as follows:

ARRIVAL: In this event, the simulation checks the unused reserved credit units status [Figure 5.1(C.1)]. If the unused reserved credit units can support an MTC record transmission, simulation deducts the credit units from current C_u [Figure 5.1(C.4)] and generates the next ARRIVAL event [Figure 5.1(C.5)]; If the unused reserved credit units can not support an MTC record transmission, simulation checks whether CCR_ValidityTimer is in the event list or not. [Figure 5.1(C.2)]. If CCR_ValidityTimer is not in the event list, it means that there are no reserved credit units in the PCEF. Consequently, the simulation generates the next CCR_INITIAL and inserts the previous deleted ARRIVAL event into event list [Figure 5.1(C.3)]; If CCR_ValidityTimer is in the event list, it represents that there are not enough unused reserved credit units in the PCEF. Thus, simulation generates the next CCR_TERMINATE event and inserts the previous deleted ARRIVAL event into the event list [Figure 5.1(C.6)].

CCR_INITIAL: In this event, reserve unit operation is activated (i.e.,PCEF sends CCR(INITIAL-REQUEST) message to OCS and then reserve credit units to PCEF) [Figure 5.1(D.1)]. Then, simulation generates the next CCR_ValidityTimer event and insert it into the event list (i.e., OCS sets the validity time) [Figure 5.1(D.2)].

CCR_TERMINATE: In this event, debiting unit operation is activated (i.e., PCEF sends CCR(TERMINATION-REQUEST) message to OCS)[Figure 5.1(E.1)]. Running CCR_TERMINATE event represents that simulation completes an MECR procedure.

CCR_ValidityTimer: In this event, simulation checks this CCR_ValidityTimer event whether exactly exists or not. If CCR_ValidityTimer event does not exist, simulation executes step F.3 [Figure 5.1(F.3)] and then simulation continues; If

CCR_ValidityTimer event truly exists, debiting unit operation will be activate (i.e., PCEF sends CCR(TERMINATION-REQUEST) message to OCS) and then simulation records unused reserved credit units and returns it to OCS. [Figure 5.1(F.2)].

If the simulation completes $1,000,000$ times, the simulation calculates all the output measures and finishes simulation [Figure 5.1(A.4) and (A.5)]. Otherwise, the simulation will keep processing the next event.

5.2 MECR Procedure

This section validates the analytical model of MECR procedure. We investigate the effects of MTC record arrival rate λ, the amount of reserved credit units θ ,and credit validity timer T on the output metrics, including $E[N]$, $E[C_u]$,and $E[C_{ru}]$. To investigate the reduction of signal overhead for OCS, we calculate amount of CCR message reduction as $\frac{E[N]-1}{E[N]}$. We set $\theta = m * c_{\mathtt{mtc}}$ to support at most m MTC records transmission by one credit reservation procedure. We assume that the inter-arrival times for an MTC record follow an exponential distribution with mean λ and variance V.

5.2.1 Effect of the MTC records arrival rate λ

Figure 5.2 investigates the $E[N]$, $E[C_u]$, and $E[C_{ru}]$ against λ under three different values of m, where $T = 50$ time units. Figure 5.2(a) plots the number of average MTC records containing in one CDR $E[N]$ against MTC record arrival rate λ. When the MTC record arrival rate λ increases, $E[N]$ increases. This phenomenon implies that the signal overhead on CCR message reduces (see Figure 5.2(d)). The result of Figure 5.2(b) is consistent with that in Figure 5.2(a). It shows that the more MTC record contains in one CDR, the fewer credit units return to the OCS at each MECR procedure. Figure 5.2(c) plots the $E[C_{ru}]$ against the λ. When $\lambda < 10^{-1}$, $E[C_{ru}]$ increases as λ increases. However, when $\lambda > 0.5$, $E[C_{ru}]$ first decrease and then converge to its minimal. The discrepancies between analytic analysis (specifically, Eqs.

Table 5.2: Comparison of the analytic and simulation results for MECR procedure ($T = 50$ time units and $m = 60$)

λ	$E[N]$			$E[C_u]$			$E[C_{ru}]$		
	Ana.	Sim.	Error(%)	Ana.	Sim.	Error(%)	Ana.	Sim.	Error(%)
0.01	1.500	1.501	0.09%	58.500	58.499	0.09%	19.583	19.602	0.09%
0.03	2.500	2.502	0.15%	57.500	57.498	0.16%	34.950	34.952	0.00%
0.05	3.500	3.498	0.23%	56.500	56.502	0.23%	41.250	41.270	0.05%
0.07	4.500	4.502	0.23%	55.500	55.498	0.23%	44.528	44.522	0.01%
0.09	5.500	5.502	0.23%	54.500	54.498	0.23%	46.432	46.438	0.01%
0.10	6.000	6.001	0.10%	54.000	53.999	0.10%	47.083	47.066	0.04%
0.30	16.000	16.001	0.06%	44.000	43.999	0.06%	48.281	48.263	0.04%
0.50	26.000	26.005	0.52%	34.000	33.995	0.52%	44.712	44.722	0.02%
0.70	36.000	36.001	0.11%	24.000	23.999	0.11%	40.343	40.353	0.02%
0.90	45.939	45.946	0.63%	14.061	14.054	0.63%	35.397	35.739	0.97%
1.00	50.624	50.634	1.00%	9.376	9.366	1.00%	33.101	33.586	1.46%
3.00	60.000	60.000	0.00%	0.000	0.000	0.00%	29.500	29.506	0.02%

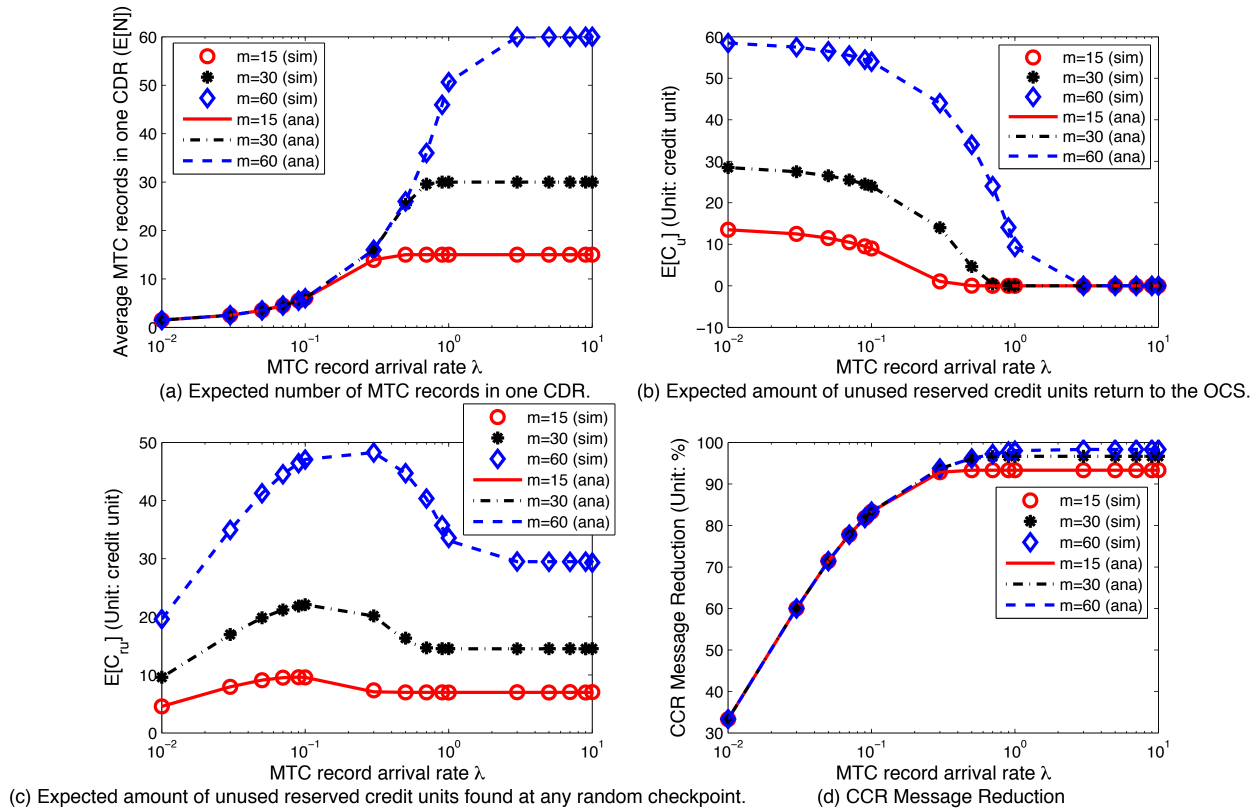
(4.5), (4.6) and (4.18)) and simulation are within 2% as shown in Table 5.2.

5.2.2 Effect of the validity time T

Figure 5.3 investigates the $E[N]$, $E[C_u]$, and $E[C_{ru}]$ against T under three different values of λ, where $m = 60$. Figure 5.3 (a) plots the number of average MTC records containing in one CDR $E[N]$ against credit validity timer T. When the credit validity timer T increases, $E[N]$ increases. This phenomenon implies that the signal overhead on CCR message reduces (see Figure 5.3(d)). The result of Figure 5.3(b) is consistent with that in Figure 5.3(a). It shows that the more MTC record contains in one CDR, the fewer credit units return to the OCS at each MECR procedure. Figure 5.3(c) plots the $E[C_{ru}]$ against the T. At first, $E[C_{ru}]$ increases as T increases. However, when T increases to its value, $E[C_{ru}]$ first decrease and then converge to its minimal. The discrepancies between analytic analysis (specifically, Eqs. (4.5), (4.6) and (4.18)) and simulation are within 2% as shown in Table 5.3.

5.2.3 Effect of the reserved credit units θ

The $\theta = m * c_{mtc}$ and we set $c_{mtc} = 1$, so we can use θ and m both. Figure 5.4 investigates the $E[N]$, $E[C_u]$, and $E[C_{ru}]$ against θ under three different values of λ, where



(a) Expected number of MTC records in one CDR.

(b) Expected amount of unused reserved credit units return to the OCS.

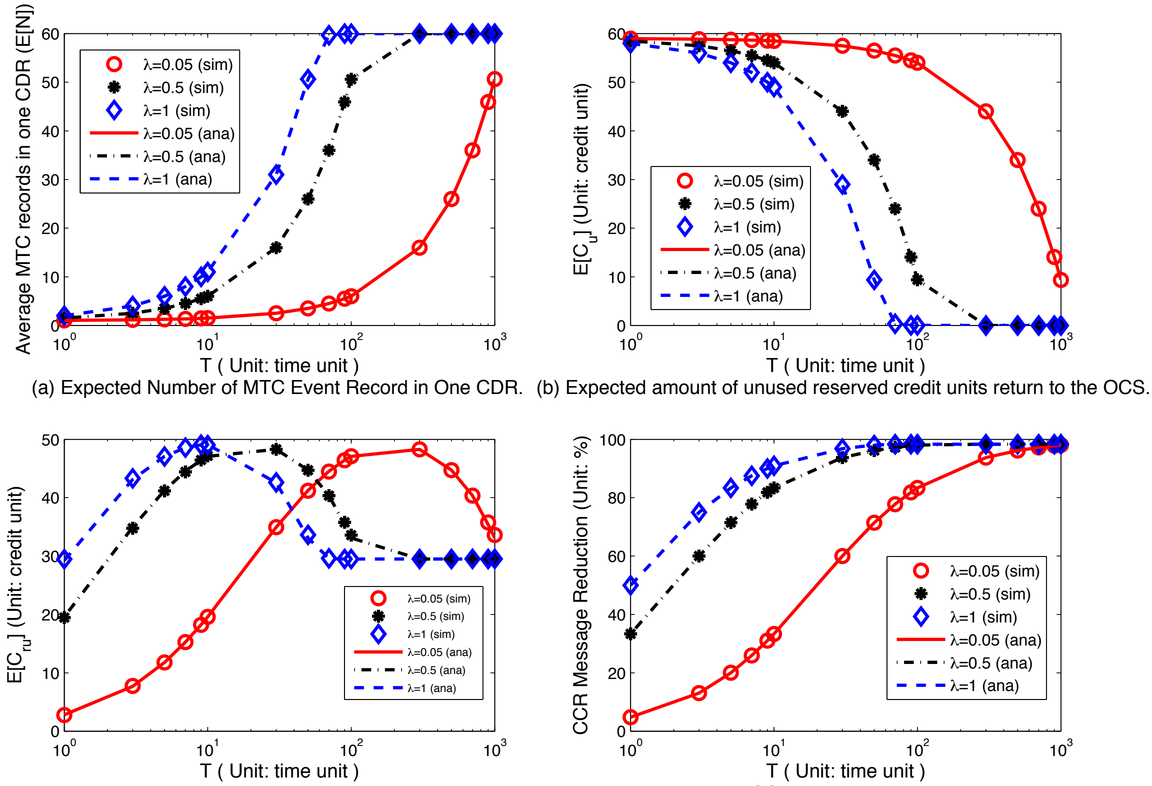
(c) Expected amount of unused reserved credit units found at any random checkpoint.

(d) CCR Message Reduction

Figure 5.2: Effects of λ and m. ($T = 50$ time units)

Table 5.3: Comparison of the analytic and simulation results for MECR procedure ($\lambda = 1$ and $m = 60$)

T	$E[N]$			$E[C_u]$			$E[C_{ru}]$		
	Ana.	Sim.	Error(%)	Ana.	Sim.	Error(%)	Ana.	Sim.	Error(%)
1	2.000	1.999	0.15%	58.000	58.002	0.15%	29.250	29.478	0.78%
3	4.000	3.998	0.22%	56.000	56.002	0.22%	43.125	43.314	0.44%
5	6.000	6.002	0.17%	54.000	53.998	0.17%	47.083	47.043	0.09%
7	8.000	8.001	0.07%	52.000	51.999	0.07%	48.563	48.570	0.02%
9	10.000	10.001	0.11%	50.000	49.999	0.11%	49.050	49.082	0.07%
10	11.000	11.005	0.51%	49.000	48.995	0.51%	49.091	49.020	0.15%
30	31.000	30.999	0.07%	29.000	29.001	0.07%	42.581	42.609	0.07%
50	50.624	50.641	1.66%	9.376	9.359	1.66%	33.101	33.630	1.60%
70	59.670	59.664	0.65%	0.330	0.336	0.65%	29.577	29.607	0.10%
90	59.999	59.999	0.02%	0.001	0.001	0.02%	29.500	29.492	0.03%
100	60.000	60.000	0.00%	0.000	0.000	0.00%	29.500	29.497	0.01%



(a) Expected Number of MTC Event Record in One CDR. (b) Expected amount of unused reserved credit units return to the OCS.

(c) Expected amount of unused reserved credit units found at any random checkpoint. (d) CCR Message Reduction

Figure 5.3: Effects of T and λ. ($\theta = 60$ credit units)

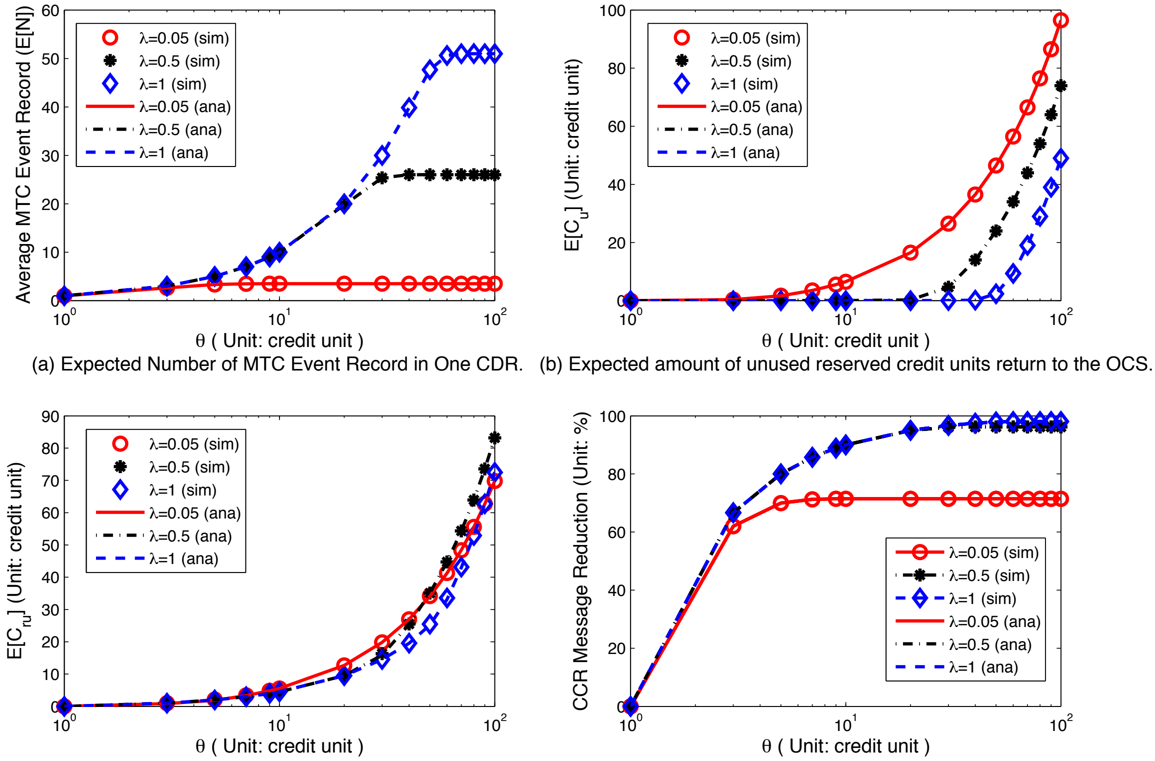
Table 5.4: Comparison of the analytic and simulation result for MECR procedure ($\lambda = 1$ and $T = 50$ time units)

m	$E[N]$			$E[C_u]$			$E[C_{ru}]$		
	Ana.	Sim.	Error(%)	Ana.	Sim.	Error(%)	Ana.	Sim.	Error(%)
20	20.00	20.000	0.00%	20.000	0.000	0.00%	20.000	9.513	0.14%
30	30.00	29.999	0.01%	29.999	0.001	0.00%	29.999	14.513	0.09%
40	39.85	39.849	0.17%	39.850	0.151	0.16%	39.850	19.560	0.19%
50	47.66	47.661	0.44%	47.665	2.340	0.45%	47.665	25.474	1.15%
60	50.62	50.637	1.32%	50.624	9.363	1.32%	50.624	33.586	1.47%
70	50.99	50.983	0.37%	50.987	19.017	0.37%	50.987	43.139	0.36%
80	51.00	51.004	0.42%	51.000	28.996	0.42%	51.000	52.913	0.05%
90	51.00	50.993	0.73%	51.000	39.007	0.73%	51.000	62.729	0.03%
100	51.00	50.999	0.10%	51.000	49.001	0.10%	51.000	72.482	0.09%

$T = 100$ time units. Figure 5.4(a) plots the number of average MTC records containing in one CDR $E[N]$ against reserved credit units θ. Under the same MTC records arrival rate, when the reserved credit units θ increases, E[N] increases. This phenomenon implies that the signal overhead on CCR message reduces (see Figure 5.4(d)). However, when we keep increasing θ value, $E[N]$ and CCR message reduction will converge. On the other hand, the different of MTC arrival rate also result to different $E[N]$ convergence value. This phenomenon implies that if we reserve too many credit units to PCRF under the same MTC arrival rate, it will not efficient to manage credit units in OCS. Figure 5.4(b) and (c) is consistent with our intuition that when we reserve more credit, the more unused reserved credit units will be generate. The discrepancies between analytic analysis (specifically, Eqs. (4.5), (4.6) and (4.18)) and simulation are within 2% as shown in Table 5.4.

5.2.4 Effect of the variance V of inter-arrival times of MTC records

Figure 5.5 investigates the performance metrics for MECR procedure against different variance V of inter-arrival times of MTC records under three different values of m, where $T = 50$ time units. Figure 5.5(a) plots the number of average MTC records containing in one CDR $E[N]$ against the variance V of inter-arrival times of MTC records.



(a) Expected Number of MTC Event Record in One CDR.

(b) Expected amount of unused reserved credit units return to the OCS.

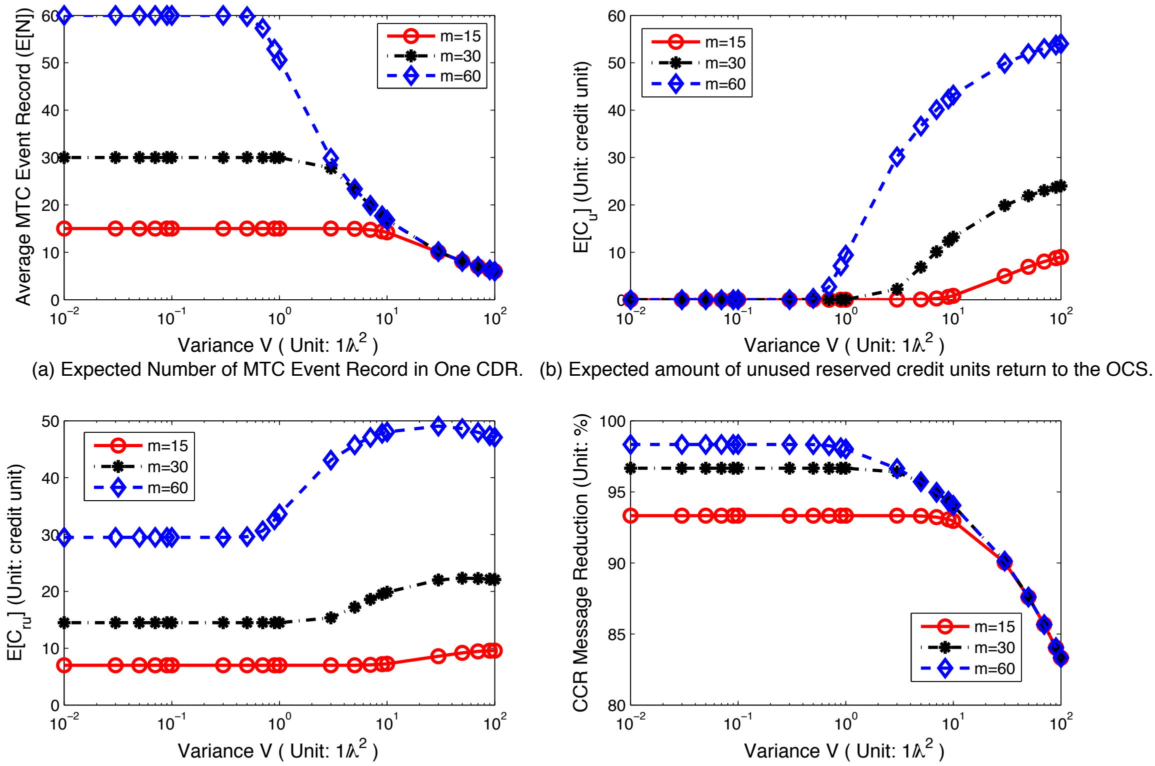
(c) Expected amount of unused reserved credit units found at any random checkpoint.

(d) CCR Message Reduction

Figure 5.4: Effects of θ and λ. ($T = 50$ time units)

This figure shows that $E[N]$ is a decreasing function of V and $E[N]$ is more sensitive to the change of V when m is large than when m is small. An interesting observation is that $E[N]$ does not change much for all cases when $V < 0.7/\lambda^2$. Figure 5.5(b) plots the average credit units return to the OCS at each MECR procedure $E[C_u]$ against the variance V under three different m settings. Surprisingly, $E[C_u]$ is an increasing function of V and $E[C_u]$ is more sensitive to the change of V when m is large than when m is small.

Figure 5.5(c) plots the unused reserved credit units found at any random checkpoint $E[C_{ru}]$ against the variance V under three different m settings. At first, the $E[C_{ru}]$ does not change much for all cases when V increases. Then, $E[C_{ru}]$ increases as V increases. However, when V increases to its value, $E[C_{ru}]$ reaches maximum and starts to decrease. Figure 5.5(d) plots the CCR message reduction against the variance V under three different m settings. This figure shows that CCR message reduction is a decreasing function of V and CCR message reduction is more sensitive to the change of V when m is large than when m is small.



(a) Expected Number of MTC Event Record in One CDR.

(b) Expected amount of unused reserved credit units return to the OCS.

(c) Expected amount of unused reserved credit units found at any random checkpoint.

(d) CCR Message Reduction

Figure 5.5: Effects of the variance V of inter-arrival times of MTC records. ($T = 50$ time units)