Winter 12-4-2009

Unconventional Negotiation: Survey and New Directions

Kwang Mong Sim

UNCONVENTIONAL NEGOTIATION: SURVEY AND NEW DIRECTIONS

Kwang Mong Sim
Department of Information and Communications, Gwangju Institute of Science and Technology, South Korea.
E-mail: kmsim@gist.ac.kr http://www.infcom.gist.ac.kr/~kmsim/MAS/

Abstract

The increasing demand for building large-scale complex and distributed systems such as Cloud/Grid computing systems accentuates the need for complex negotiation mechanisms for managing computing resources. The contribution of this paper includes: 1) summarizing classical negotiation problems and conventional negotiation in terms of the utility function, strategy, and protocol, 2) discussing the differences between conventional negotiation and unconventional negotiation, 3) reviewing and comparing the state-of-the-art developments in both relaxed-criteria negotiation, and complex and concurrent negotiation, and 4) suggesting new directions in complex negotiation and its applications.

Introduction

Negotiation denotes the process of two or more agents (with disparate interests) searching for an agreement on some issues (e.g., price) [1]. The search process involves exchange of information, relaxation of initial goals, and mutual concessions. Automated negotiation among distributed systems (e.g., multi-agent systems and software agents) is becoming increasingly important because automated interactions among software agents can occur in many different contexts in which conflicts and differences need to be resolved. For instance, e-negotiation is a desirable mechanism for resolving differences in trading terms in e-commerce and supply chain management, and more recently for resource (co-)allocation in Grid computing. Research on engineering e-negotiation agents has received a great deal of attention in recent years.

The contribution of this paper includes: 1) summarizing classical negotiation problems, and conventional negotiation in terms of the utility function, strategy and protocol, 2) reviewing and comparing the state-of-the-art developments in unconventional negotiation such as relaxed-criteria negotiation, and complex and concurrent negotiation, 3) discussing the differences between conventional negotiation and unconventional negotiation, and 4) suggesting new directions in concurrent negotiation and relaxed-criteria negotiation, and their applications.

Conventional Negotiation

In the literature in bargaining (negotiation), the seminal works of Nash [2], and Rubinstein and Osborne [3-4] established the essential frameworks and foundations of bargaining theory.

Bargaining Problem: In [3], a bargaining problem is specified as follows. There is a set of N bargainers (players or agents). The negotiation outcomes are: 1) agents reaching an agreement or 2) negotiation terminating with a conflict D. Each agent has a negotiation set or agreement set A (see [3, p. 9]), which represents the space of its possible deals or proposals for reaching agreements with its opponent, and the agent has a preference ordering over the set $A \cup D$. There is a utility function U for each agent that represents its preference ordering by associating each negotiation outcome with a number, such that more preferred outcomes are associated with larger numbers.

Utility function: An agreement may take many forms. It can be a price or a detailed contract that specifies the actions to be taken by agents [3]. In classical bargaining problems involving price-only negotiation between two agents B and S [3], the utility function U^B of B is defined as follows. Let IP_B and RP_B be the initial and reserve prices of B. Let D be the event in which B fails to reach an agreement with its opponent. U^B:$[IP_B,RP_B] \cup D \rightarrow [0,1]$ such that $U^B(D)=0$ and for any $l_B \in [IP_B,RP_B]$,$U^B(l_B)>U^B(D)$. Furthermore, if B is a buyer (consumer) agent, then $U^B(l_B^1) > U^B(l_B^2)$ if $l_B^1 < l_B^2$. If S is a seller (provider) agent, then $U^S(l_S^1) < U^S(l_S^2)$ if $l_S^1 < l_S^2$ such that for any $l_S \in [IP_S,RP_S]$, $U^S(l_S)>U^S(D)$.

Negotiation strategy: If B and its opponent S are sensitive to time, then let τ_B be the deadline of B, and τ_S, IP_S and RP_S be the deadline, initial price, and reserve price of S. In a one-to-one negotiation, the only factor affecting both agents is their deadline. In [5-7], B and S adopt time-dependent strategies. Let λ_B and λ_S be the time-dependent strategies of B and S, respectively. The proposal P_t^B of B at time $t, 0 \le t \le \tau_B$, is determined as follows:

$$P_t^B = IP_B + (\frac{t}{\tau_B})^{\lambda_B}(RP_B - IP_B) \qquad (4)$$

where $0 \le \lambda_B \le \infty$, and IP_B and RP_B are B's initial price and reserve price, respectively.

The proposal P_t^S of S at time $t, 0 \le t \le \tau_S$ is determined as follows:

$$P_t^S = IP_S - (\frac{t}{\tau_S})^{\lambda_S}(IP_S - RP_S) \quad (5)$$

where $0 \le \lambda_S \le \infty$, IP_S and RP_S are S's initial price and reserve price, respectively.

Negotiation protocol: Negotiation between B and S is carried out using the *Rubinstein's alternating-offers* protocol [4] as follows. B makes an offer at t = 0, 2, 4, 6, … S makes a counter offer at t = 1, 3, 5, 7, … During negotiation, B (respectively, S) uses eq. (4) (respectively, eq. (5)) to generate an offer (respectively, a counter-offer). Negotiation terminates (i) when an agreement is reached, or (ii) with a conflict when either B's or S's deadline is reached.

Optimizing utility: The problem is to find a value of λ_B (respectively, λ_S) that would optimize U^B (respectively, U^S) given different parameters (e.g., deadline, initial price, and reserve price).

Conventional Negotiation vs. Unconventional Negotiation

In this paper, conventional negotiation [1-8] approaches are identified with the following characteristics:

1. An agreement is reached when one agent proposes a deal that matches (or exceeds) what another agent asks for.
2. Agents focus only on optimizing utilities.
3. When contracts are established, agents are bound to them (i.e., no agent can breach a contract).
4. Agents negotiate with other agent(s) for one type of goods/service in only one market.

Agreements and utilities: In conventional negotiation, agents evaluate (counter-)proposals using some utility function $U(P)$ and typically accept a proposal P based on whether the opponent's proposal generates an expected payoff that is equal to or higher than some expected payoff. For example, if agent B_1's proposal P_1^B generates a payoff of $U(P_1^B)$, B_1 will typically accept another agent S_1's (counter-)proposal P_1^S only if it generates a payoff $U(P_1^S)$, such that $U(P_1^S) \ge U(P_1^B)$. Since agents in conventional negotiation mechanisms are utility-maximizing agents, they are not designed with the flexibility to consider reaching a faster agreement by accepting P_1^S if $U(P_1^S) < U(P_1^B)$ even if the difference $|U(P_1^S)\text{-}U(P_1^B)|$ is (very) small. In multi-lateral negotiation, an agent may run the risk of losing deals in the face of strong competition. The idea of *relaxed-criteria negotiation* proposed by Sim [9] redefines the notion of reaching a consensus in negotiation by allowing agents to overlook very small differences in their proposals, and hence, slightly relaxing the conditions for reaching agreements. Unlike conventional negotiation where agents only strive to optimize their utilities, in relaxed-criteria negotiation, agents attempt to enhance their success rates in negotiation and to reach faster agreements while also attempting to optimize their utilities.

Contracts: In conventional negotiation, an agent is bound to a contract once it is established (i.e., neither party can breach the contract). In unconventional negotiation, Sandholm et al. [10] proposed the idea of *leveled commitment contracts* for a two-player game, where each player can be freed from a contract by paying a penalty fee to the other player, and the level of commitment is set by breach penalties. Allowing decommitments enables an agent to profitably accommodate new negotiation events that make some old contracts unbeneficial. This enables an agent to take on unbeneficial contracts in anticipation of better contracts in subsequent negotiations. For example, in Grid resource negotiation, the reasons for allowing decommitments are as follows: 1) if a consumer cannot acquire ALL its required resources before its deadline, it can release those resources acquired so that resource providers can assign them to other consumers, and 2) decommitment allows an agent that has already reached an intermediate contract for a resource to continue to search for better deals before the termination of the entire concurrent negotiation.

Markets: In conventional negotiation, regardless of the number of agents (participants), (i.e., whether it is a one-to-one, one-to-many, or many-to-many negotiations), agents negotiate for only one type of goods/service within one market. A recent work by Sim et al. [11] considered a complex concurrent negotiation mechanism in which an agent conducts *simultaneous and parallel negotiation activities* with agents in *multiple e-markets* for acquiring multiple types of resources.

Relaxed-criteria Negotiation

In Sim's relaxed-criteria negotiation [9], two rules were defined for allowing agents to reach agreements:

R1: An agreement is reached if an agent B_1 and its opponent S_1 propose deals P_1^B and P_1^S, respectively, such that either 1) $U(P_1^B) \ge U(P_1^S)$ or 2) $U(P_1^S) \ge U(P_1^B)$, where P_1^B and P_1^S represent the buying and selling prices, respectively.

R2: An agreement is reached if either 1) $\eta = U(P_1^S) - U(P_1^B)$, such that $\eta \to 0$ or 2) $\eta = U(P_1^B) - U(P_1^S)$, such that $\eta \to 0$, where η is the amount of relaxation determined using a fuzzy decision controller (*FDC*) together with a set of relaxation criteria.

In conventional negotiation, agents follow

Rubinstein's alternating-offers protocol and only use *R1* for determining whether an agreement is reached. In Sim's relaxed-criteria negotiation protocol, agents use both *R1* and *R2* for determining whether an agreement is reached.

Sim's relaxed-criteria negotiation is generally designed for many-to-many negotiation, and agents are programmed to slightly relax their bargaining terms in the face of intense pressure (e.g., urgent need to acquire a resource, or facing fast approaching deadlines). Since notions such as "very slight" difference in proposals, "strong" competition, and "fast" approaching deadline are vague, an *FDC* together with a set of 16 fuzzy rules were used in [9] to guide agents in making decisions when relaxing their aspirations. In relaxing its bargaining terms, an agent in [9] is influenced by factors such as degree of competition (ϑ) and its *eagerness* (ε). ε represents how urgent it is for an agent to acquire a resource before a deadline [9]. An agent that is *more* (respectively, *less*) eager to reach a consensus will be more likely to overlook small differences between its proposal and its opponents' counter-proposals. Both ϑ and ε are the relaxation criteria and they form the antecedents of the fuzzy rules. The amount of relaxation η is the consequent of a fuzzy rule. Whereas ϑ and ε are the inputs to the *FDC*, η represents the amount that an agent would relax its bargaining terms in a given situation (the output of the *FDC*).

In [12], the idea of relaxed-criteria negotiation was generalized by augmenting the designs of negotiation agents with additional fuzzy controllers to allow even more flexibility in negotiation. In [12], agents can both 1) raise their expectations in extremely favorable markets and 2) lower expectations in extremely unfavorable markets (i.e., relaxing their bargaining criteria). In relaxing their bargaining criteria, agents in [12] use the same set of relaxation criteria (degree of competition and eagerness) as agents in [9]. In raising their expectations, agents face two challenging decisions: 1) whether to postpone reaching consensus and 2) duration to postpone deal. In very favorable market conditions, an agent B_1 may receive (>1) proposals $\boldsymbol{O}=\{P_1^S,\ldots,P_1^S\}$ from its opponents $S_1,\ldots,S_k$ that are better than or equal to its own proposal P_1^B, such that $U(P_j^S)\geq U(P_1^B)$, $\forall P_j^S\in\boldsymbol{O}$. Hence, B_1 may postpone its decision to reach a consensus with an opponent in the hope that it can achieve a higher utility than $U(P_1^B)$. However, in multi-lateral negotiation, if B_1 postpones its decision to reach a consensus, it *also* runs the risk of not completing the deal with *any* of its opponents eventually. Hence, B_1's decision to postpone a deal depends on the *number* of agents N_a with a proposal that is better than or equal to its own proposal. If N_a is a sufficiently large number, then it would be advantageous for B_1 to postpone its deal. However, B_1 needs to determine how large N_a should be for a given market condition. For different market situations, N_a is determined by the degree of competition (ϑ) that B_1 faces and its eagerness (ε) to acquire a resource/service. If B_1 is *very* eager to acquire an urgently needed resource or faces very strong competition, it may not postpone the deal if N_a is not much larger than 1. Both ϑ and ε collectively form the antecedent of the fuzzy rules of an *FDC* (called ***FDC1*** in [12]) for determining N_a. If B_1 decides to postpone its decision to reach a deal, it has to decide the duration T_p for postponing the deal. Two factors that affect T_p are the fraction of remaining trading time $T_r=(\tau-t)/\tau$ (where τ is the deadline and t is the current round) and N_a. Both N_a and T_r collectively form the antecedent of the fuzzy rules of an *FDC* (called ***FDC2*** in [12]) for determining T_p.

Whereas slightly lowering expectation may increase the probability of reaching consensus in adverse market conditions, slightly raising expectation may enhance the utilities of agents in extremely good (albeit, rare) market situations. Stochastic simulations in [12] demonstrated that agents in [12] following the generalized relaxed-criteria negotiation protocol achieved 1) higher average utilities than agents in [9] following the relaxed-criteria protocol and 2) higher success rates than agents in [13-14] following alternating-offers protocol (i.e., agents that do not relax their bargaining terms nor raise their expectations).

Subsequently, the work in [9] was adapted to automated negotiation in Grid resource management. In Sim's relaxed-criteria G-negotiation protocol [15-16], agents representing resource providers and consumers are programmed to *slightly* relax their bargaining criteria under intense pressure (e.g., when a consumer has a higher demand for resources) with the hope of enhancing their chance of successfully acquiring resources. A consumer agent and a provider agent are both designed with an *FDC*: *FDC-C* and *FDC-P*, respectively. Two different sets of relaxation criteria (for consumers and providers, respectively) that are specific to Grid resource management are used as inputs to *FDC-C* and *FDC-P*, respectively.

Two criteria that can influence a consumer agent's decision in the amount of relaxation of bargaining terms are: 1) recent statistics in failing/succeeding in acquiring resources called *failure to success ratio* (fs_t) and 2) demand for computing resources called *demand factor* (df_t). If a consumer agent is *less* successful in acquiring resources recently to execute its set of tasks, it will be under more pressure to slightly relax its bargaining criteria with the hope of completing a deal. If a consumer agent has a *greater* demand for computing resources it is more likely to be under more pressure to slightly relax its bargaining criteria. Both fs_t and df_t are inputs to *FDC-C*, and the output is η (the amount of relaxation) [15-16].

Two criteria that can influence a provider agent's decision are: 1) the amount of the provider's resource(s) being utilized (the *utilization level* (ul_t)) and 2) recent resource requests from consumers (the *request factor* (rf_t)). If more of its resources are currently being utilized or are occupied, then a provider is less likely to slightly relax its bargaining terms. If there are fewer recent demands from consumers for resources, a provider is more likely to slightly relax its bargaining criteria since it is under more pressure to lease out its idle resources. Both ul_t and rf_t are inputs to *FDC-P*, and the output is η [15-16].

The fuzzy rules for *FDC-C* and *FDC-P* in [15-16] and the *FDC* in [9] were manually generated, and agents in [9] and [15-16] negotiate in only one market. In [17], relaxed-criteria negotiation agents were designed to *negotiate in more than one e-market* and with the capability to continuously enhance their performance by evolving their fuzzy rules as they negotiate in more e-markets. Like agents in [9, 15-16], agents in [17] also follow Sim's relaxed-criteria negotiation protocol. Whereas there are two inputs to *FDC-C* and *FDC-P* in [15-16] and the *FDC* in [9], there are three inputs to the *FDC* in [17]. The three inputs corresponding to the set of relaxation-criteria are: 1) time pressure, 2) degree of competition, and 3) the relative distances from the opponents' proposals. When an agent's deadline is fast approaching, an agent is under more (time) pressure to relax its bargaining criteria. Hence, at the start of negotiation, an agent is less likely to overlook small differences in proposals. Like agents in [9], an agent in [17] that faces more (respectively, less) competition is more (respectively, less) likely to relax its bargaining criteria to reach an agreement. Another criterion for relaxation is the relative distances between the proposal of an agent and all the proposals of its opponents. The general idea is that if the best proposal from an agent's opponent is very close to its own proposal relative to all other proposals from all other opponents, then it seems prudent that an agent should relax its bargaining terms and reach a consensus with the opponent with the best proposal. The impetus of the work in [17] is using an evolutionary procedure for learning effective relaxed-criteria negotiation rules that will enhance the performance of agents in terms of negotiation success rates, utility, and negotiation speed. Using the negotiation outcomes (success rates, utility, and negotiation speed) of agents in each e-market as data sets, at the termination of the negotiation process for each e-market, a *GA* is executed to evolve a new set of fuzzy relaxed-criteria rules of agents. The new and enhanced set of fuzzy rules will be adopted to guide agents in relaxing bargaining terms when it negotiates in a new e-market, and this process continues as agents improve their performance as they negotiate in new and different e-markets. This self-improving characteristic represents the latest state of development in relaxed-criteria negotiation.

Concurrent and Complex Negotiation

This section reviews complex negotiation in which agents conduct concurrent and simultaneous negotiation activities, and can potentially be freed from intermediate contracts by paying penalty fees.

Rahwan et al.'s [18] one-to-many negotiation model consists of one buyer and multiple sellers, and the buyer has a number of sub-negotiators. There are multiple negotiation threads, and in each negotiation thread, each different sub-negotiator conducts a one-to-one negotiation with a different seller. Four strategies were proposed in [18] for controlling and coordinating multiple simultaneous one-to-one negotiations: 1) *Desperate Coordination Strategy (DCS)*, 2) *Patient Coordination Strategy (PCS)*, 3) *Optimized Patient Coordination Strategy (OPCS)*, and 4) *Strategy Manipulation Coordination Strategy (SMCS)*. In *DCS*, the coordinator agent terminates all negotiations once *any* negotiation thread reaches an agreement. In *PCS*, the coordinator agent waits until all sub-negotiators have completed negotiation, then chooses the best offer. In *OPCS*, the coordinator uses the negotiation outcome from a negotiation thread to influence the performance of other negotiation threads. For example (see [18, p. 201]), if one sub-negotiation found a deal with utility 7, then in other negotiation threads, any offers with utility lower than 7 will be considered unacceptable. In *SMCS*, the coordinator may modify the negotiation strategies of different negotiation threads at runtime. For instance, if a deal has been secured in one negotiation thread, the consumer can adopt a "take-it-or-leave-it" strategy in other negotiation threads [18, p. 201].

Ngyuen et al. [19] also proposed a one-to-many negotiation model consisting of multiple *concurrent* one-to-one negotiations. Unlike agents in [18], agents in [19] adopt the time-dependent concession-making strategies in [7]: 1) *Conceder* (quickly conceding to its reservation value), 2) *linear* strategy conceding to its reservation value, and 3) *Bouleware* (maintaining its value until the deadline is almost reached, then rapidly conceding to its reservation value). [19] introduced more flexibility to their concurrent one-to-one negotiation model by allowing buyer and seller agents to renege on deals (i.e., decommit deals) at the expense of paying penalty fees. Whereas [10] proposed *leveled* *commitment contracts* for a two-player game, [19] extended the work in [10] to concurrent negotiation involving *one* buyer and *many* sellers, and included two additional features: 1) reasoning about *when* to decommit from a contract and 2) determining whether a new contract is acceptable by considering decommitment thresholds. In [19], the penalty fee is dynamically computed as a percentage of the utility of the deal and the time when the contract is broken. A new contract is acceptable if the utility gained by taking the new contract is greater than that of the current contract after paying the penalty fee for decommitment, and the degree of acceptance is above a predefined threshold θ that specifies the extent that a buyer agent should accept proposals. A buyer agent in [19] adopts either of the two commitment management strategies: *greedy* (θ=0) (tends to accept any possible deal) or *patient* (θ = 0.5) (only deals that provide a certain expected utility value will be accepted). Additionally, there are two types of provider agents in [19]: *loyal provider*s that will never renege on contracts and *partial providers* that will possibly renege on contracts.

Sim et al. [11] proposed a concurrent negotiation model consisting of multiple one-to-many negotiations. Designed for bolstering Grid resource co-allocation, the concurrent negotiation model consists of a coordinator which coordinates the parallel negotiation activities for acquiring *n* different types of Grid resources in *n* different resource markets. In each resource market, a consumer agent negotiates simultaneously with multiple resource provider agents for one type of Grid resource. Furthermore, both consumer and provider agents can be freed from a contract by paying penalty fees to their opponents. In negotiating for one type of Grid resource in a resource market, there is a commitment manager that manages both commitments and decommitments of (intermediate) contracts. In [11], three classes of commitment management strategies (CMSs): {*Linear*-CMS, *Conciliatory*-CMS, and *Conservative*-CMS} were defined by combining the commitment management steps with the time-dependent concession making functions in [6]: 1) *conservative* (maintaining the initial price until an agent's deadline is almost reached), 2) *conciliatory* (conceding rapidly to the reserve price), and 3) *linear* (conceding linearly). In [20], Sim et al. adopted an *Adaptive*-CMS in which the commitment management steps were combined with an adaptive concession making strategy. An agent's adaptive concession making strategy in [20] is derived from its current bargaining position in a resource market. For instance, a consumer agent is in an *advantageous* (respectively, a *disadvantageous*) bargaining position if it is negotiating in a resource market with more (respectively, fewer) provider agents. The coordinator can coordinate the parallel negotiation activities in *n* resource markets using: 1) the Utility-oriented Coordination Strategy (*UOCS*) and 2) the Patient Coordination Strategy (*PCS*). In the *UOCS*, at each negotiation round, the coordinator determines whether to terminate the entire concurrent negotiation based on the predicted utility changes received from every commitment manager for each one-to-many negotiation. In the *PCS*, the coordinator terminates all concurrent negotiations when it acquires *all* required resources without considering time constraint. In [20], the prediction in the change of utilities in the *UOCS* was enhanced using linear regression (the Regression-based Utility-oriented Coordination Strategy (*RUOCS*)). Favorable empirical results in [20] show that agents adopting the *RUOCS* achieved the highest final utilities among the three coordination strategies (*RUOCS, UOCS,* and *PCS*).

Conclusion and New Directions

This paper has discussed the differences between conventional negotiation and unconventional negotiation and summarized the state-of-the-art developments in both relaxed-criteria negotiation, and complex and concurrent negotiation.

Whereas game-theoretic research [2-4] provides solution concepts for optimizing agents' utilities in simpler negotiation settings (e.g., one-to-one negotiation), relaxed-criteria negotiation offers a novel approach in solving much more complex negotiation problems using heuristics to improve success rates and negotiation speed. Whereas researchers in game theory [2-4] provided solution concepts for determining equilibrium strategies for negotiation, they did not provide techniques for computing and finding these equilibrium strategies, and [21] has shown that finding the equilibrium strategies is NP-hard even in a simple one-to-one negotiation setting. Through empirical studies, relaxed-criteria negotiation aims at providing an alternative means for studying the behaviors of negotiation agents in complex environments.

In conventional negotiation, participants negotiate in the same market (i.e., within one market). In concurrent negotiation, a participant conducts *simultaneous and parallel negotiation activities* with resource providers *in multiple e-markets* to acquire multiple types of resources. Furthermore, in complex negotiation, both buyers and sellers can renege on (intermediate) contracts by paying penalty fees. In conventional negotiation, agents negotiate only in one e-market for one product/service, and the attributes that may complicate the design of negotiation mechanisms include: 1) the number of negotiation participants and 2) the number of issues involved in negotiation. In complex negotiation involving decommitments and parallel negotiation activities in multiple e-markets, there are two additional attributes that contribute to the complexity in concurrent negotiation: 1) the number of e-markets that an agent is involved in and 2) the number of times that contracts are breached before negotiation terminates.

New direction: The increasing demand for building large-scale complex and distributed systems such as Cloud/Grid computing systems accentuates the need for complex negotiation mechanisms for managing computing resources. Supporting resource co-allocation is essential for Grid computing because 1) computationally intensive applications often require more resources than a single computing machine can provide, and 2) an application may require multiple types of computing capabilities from different resource owners [22]. Successfully obtaining contracts from multiple resource owners for simultaneously accessing several resources is a very challenging task given that stakeholders often have different requirements. Allocating multiple resources in a coordinated fashion across virtual organizational boundaries is also a very difficult problem (e.g., mapping application workflows consisting of interacting components that need to be executed in a certain partial order to Grid resources is an *NP* complete problem [23]). One way of solving such a hard problem is to use heuristic approaches (e.g., relaxed-criteria negotiation). This paper suggests that a relaxed-criteria concurrent negotiation mechanism may be an appropriate tool for facilitating Grid resource co-allocation. In a relaxed-criteria concurrent negotiation mechanism, 1) agents in a Grid resource market follow a relaxed-criteria negotiation protocol, and perhaps adopt a set of criteria in [15-16] (i.e., *failure to success ratio*, *demand factor*, *utilization level*, and *request factor*), for relaxing bargaining terms, and 2) coordination of the parallel negotiation activities may be achieved by adopting one of the three coordination strategies in [11, 20] (*RUOCS, UOCS,* and *PCS*).

Acknowledgement. This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST 2009-0065329) and DASAN International Faculty Fund (project code: 140316).

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