Agent Based Economic Scheme for Seamless Job Scheduling in Bandwidth Constrained Wireless Grids

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Abstract

The bandwidth constraints, frequent disconnections and device mobility will affect the resource availability in a wireless grid. The device mobility from one cell to another has diverse impact on job execution. Due to limited resources and rational users, users may not be willing to share the resources. Scheduling of grid jobs in a complex, heterogeneous, resource constrained and dynamic wireless grid environment is challenging. This paper proposes a scheme for seamless job scheduling by using software agents in bandwidth constrained wireless grids. An economic scheme by using non-cooperative bargaining game is designed to encourage resource sharing depending upon grid market dynamics. The scheme consists of two agencies: grid information service and resource broker agency. The agents in agencies interact and cooperate with each other to discover reliable devices, negotiate resource cost and bandwidth, and support seamless job execution. Based on the mobility of a device, agents decide dynamically either to continue or terminate execution of a scheduled job. The scheme is simulated to evaluate the performance parameters such as expected surplus, job completion time and job execution rate. We observed that the proposed scheme performs better than the existing work.

1 Introduction

The advancements in wireless and mobile technologies have increased the capabilities of wireless devices such as laptop, wireless PC, PDA, cell phone and sensor. The increasing number of wireless/mobile device users and developments in grid technology have paved the way for wireless grid evolution. Wireless grid is a large scale, complex, heterogeneous, distributed wireless network environment in which resource consumers and providers from different administrative domains have different policies, preferences, and goals [1, 2, 3]. It is a relevant and prominent technology for some of the promising applications like disaster management, medical sciences, emergency communication, weather forecasting, automobile industry, etc. In wireless grid the consumers prefer more reliable and cheaper resources, whereas providers prefer efficient utilization of resources and more profit by enforcing the local control on policy of resource usage. Also, consumers prefer more bandwidth to reduce communication delay whereas providers prefer lesser bandwidth per consumer so that they can provide service to more consumers.

New emerging computationally intensive applications require huge amount of different types of resources such as processing power, memory and bandwidth for execution. User applications are submitted to a grid with requirement specifications like maximum affordable price, minimum bandwidth required, job deadline, number of processors, memory and storage, etc. The device (or user) mobility and frequent disconnections in a wireless grid affects the resource availability thereby causing devices to become unreliable for job scheduling. Wireless devices are resource constrained, i.e., they have less battery power, limited bandwidth, lesser processing capacity and memory. Due to constrained resources, users tend to be selfish by not willing to share their resources but are ready to utilize other device's resources. Thus, a proper job scheduling scheme is needed that offers some credentials for resource sharing and ensures successful job execution.

This paper proposes a scheme for seamless job scheduling in bandwidth constrained wireless grids by using software agents. An economic scheme to negotiate resource cost and bandwidth by considering grid market dynamics is employed. Based on the mobility of a device, an agent decides dynamically whether the jobs scheduled to device should either continue or terminate their execution. If a device moves out of local MSC (Mobile Switching Center) range, then jobs are rescheduled to another reliable device for successful completion.

An agent is a software entity, which senses an environment and acts upon it by using knowledge base to achieve the specified goals [4]. The mandatory properties (like autonomy, reactive and proactive) and orthogonal properties (like communicative, mobility and learning) of agents compel agent technology as a popular solution in the context of wireless grids for different services such as monitoring, service discovery, scheduling, negotiation and so on. We consider a non-cooperative bargaining game in designing of an economic scheme [5]. In a non-cooperative bargaining game, the players make choices out of own interest without knowing any information about an opponent. Due to the conflict of interest between the providers and consumers, such a game suits well to formulate an economic scheme in a realistic way. Each player tries to maximize his/her payoff. The payoff (utility, profit, surplus) is a measure of the usefulness of an allocation option to the owner of tasks and grid resources. During bargaining, players offer discounts and attempt to reach a mutual agreement to make a surplus. Discount indicates the penalty afflicted on the surplus of a player during bargaining. To speed up bargaining process, players observe their current negotiation status (position) and offer discounts by using either aggressive or conservative or linear discount strategy.

1.1 Related Works

For task allocation and resource management in a grid, an efficient non-linear task workload prediction mechanism is proposed in [6] by using a fair scheduling algorithm. The Akogrimo project presented in [7] aims at developing an integrated service architecture for commercial mobile grids. It discusses architecture and key characteristics of Akogrimo integrating mobility and network layer QoS support in a commercial grid environment to support efficient resource sharing. Various ways of implementing a pricing strategy for cost-optimal job allocation are given in [8, 9]. A continuous double auction protocol with discriminatory pricing policy is used as an economic approach to share idle processor time among the nodes in a dynamic ad-hoc grid in [10, 11]. Here, the nodes participate with a limited budget and increase or decrease their budget while selling or buying the resources.

They adopt a dynamic pricing strategy to decide a price by using their previous experiences in the grid. There are some works on resource allocation based on cooperative game theory where agents share same desires and have complete information about the world [12, 13, 14]. But, practically most of the times, agents have private information where they do not reveal their strategies, constraints and/or preferences. There are some works based on non-cooperative game theory where agents are self-interested and have incomplete information [15, 16, 17, 18].

The works given in [19, 20, 21] considered resource allocation in a mobile grid consisting of mobile nodes and wireless access point (WAP) server (acting as the job allocator). WAP server bargains with mobile nodes (resource providers) to purchase resources to provide services to grid community. The bargaining is modeled as an incomplete information, non-cooperative and alternating offer bargaining game between two players. The work is extended in [3] to present a node mobility tracking scheme based on IEEE 802.11 architecture. Mobility prediction framework is required to estimate the number of nodes potentially available for job allocation during a given scheduling time. It also formulates a fair pricing strategy to determine an amount user has to pay to resource providers.

There are many works on negotiation mechanisms that use negotiation agents in a grid for resource allocation. The state-of-the-art approaches of grid resource negotiation mechanisms are reviewed and discussed in terms of their strategies and protocols in [22].

A two-phase bargaining protocol is adopted in [23] for resource allocation. It consists of two phases called a distributive negotiation phase (where self-interested agents adopt heuristic strategies to exchange offers among themselves) and an integrative negotiation phase (where agents try to find joint gains while trying to maintain the utility outcome from the distributive negotiation phase). A rule-based framework for automated negotiation in service contracts is proposed in [24]. The works given in [25, 26] adopt a market-driven strategy and a relaxed-criteria protocol for resource negotiation in a grid. Negotiation agents are programmed to relax their bargaining criteria slightly depending on resource demand so that they can acquire resources successfully. Also they adopt a market-driven strategy to consider the market dynamics like adding or removing resources and services from a grid.

In aforesaid related works, we observe some limitations: (1) negotiation mechanisms do not consider the dynamics of a grid market, (2) agents bargaining strategy is defined only in terms of the remaining time for negotiation without considering the current negotiation status of an agent, (3) bandwidth is not taken into account while bargaining (except in [21]), which is a critical resource in a wireless grid, (4) do not consider rescheduling of jobs with device mobility, and (5) lack scalability, flexibility and adaptability.

1.2 Our Contributions

To overcome the above mentioned limitations of existing works, we propose a scheme for seamless job scheduling in bandwidth constrained wireless grids by using agents. The scheme consists of two agencies: (1) *Grid Information Service (GIS) agency* consisting of a RR (resource repository) and four agents - Grid Monitoring Agent (GMA), Actual Organization Monitoring Agent (AOMA), Mobility Management Agent (MMA), and Assistant Agent (AA). It monitors device mobility, controls device state such that it does not get overloaded and provides resource availability information at any instant of time to aid job scheduling. (2) *Resource Broker (RB) agency* consisting of three agents - Matchmaker

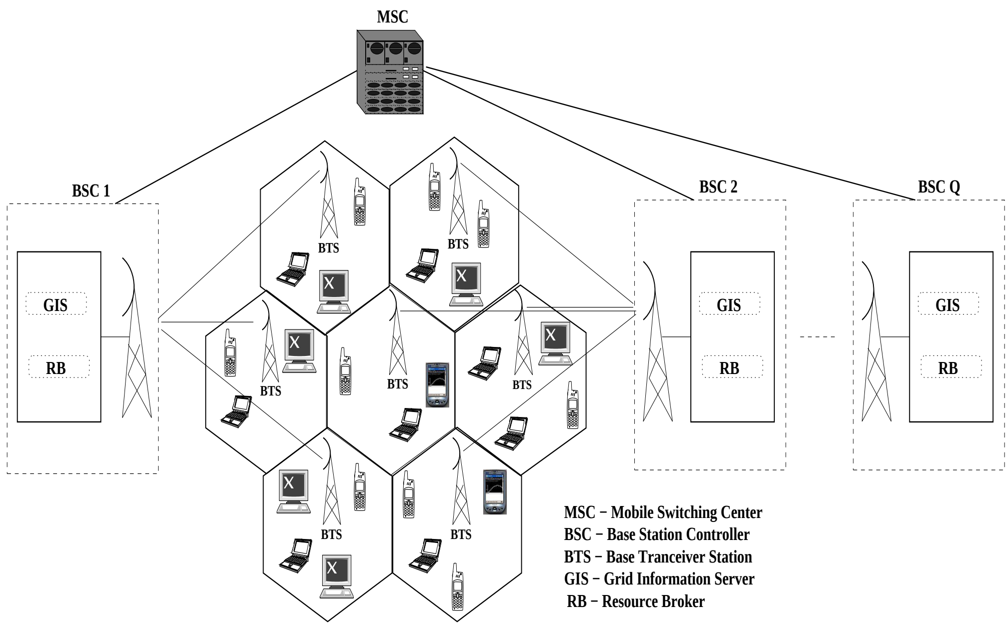

Figure 1. Wireless grid environment

agent (MA), Negotiation agent (NA) and Job allocation agent (JAA). It discovers reliable devices, negotiates resource cost and bandwidth by using an economic scheme and schedules jobs for seamless execution. The contributions of the proposed scheme which differ from existing works are as follows.

- Design of scalable, flexible, and adaptable multiagent architecture for job scheduling;
- Design of an economic scheme to negotiate resource cost and bandwidth by considering grid market dynamics;
- Identification of negotiation status (position) and adapting the negotiation process accordingly by using different discount strategies.
- Design of seamless job scheduling by considering device mobility.

The rest of the paper is organized as follows. Section 2 describes the wireless grid environment, section 3 describes device reliability and an economic model. The proposed seamless job scheduling scheme with architecture, agencies and algorithm is presented in section 4. Section 5 discusses the simulation results. Conclusions are given in section 6.

2 Wireless Grid Environment

A typical wireless grid environment based on cellular network is depicted in Figure 1 for designing the proposed seamless job scheduling scheme. A mobile switching center (MSC) has several Base Station Controllers (BSCs), and each BSC covers some Base Transceiver Stations (BTSs). BSC is comprised of a Grid Information Server (GIS) and a Resource Broker (RB) to facilitate various grid services. Each cell represents an actual organization having some number of wireless devices. Each wireless device communicates with a GIS and/or RB through a BTS of cell. Air interface is used between BTS and wireless devices whereas other components are connected physically by wires.

Each device can act as resource provider as well as resource consumer. Wireless device consists of resources like processor, memory, bandwidth, etc. The resource state changes dynamically depending on the number of jobs allocated/running, device mobility, signal strength, and battery power. The GIS stores the resource information of all wireless devices in its database called resource repository. The RB receives jobs from the grid users and obtains resource information from the GIS to discover the relevant devices for job execution.

3 Mathematical Models

This section describes the design of device reliability model and non-cooperative bargaining game based economic model used in the proposed scheme.

3.1 Reliability Model

The reliability of a device, R_{D_i}, indicates device ability to perform functions in routine circumstances as well as hostile or unexpected circumstances. We consider the parameters like power consumption, availability of memory and bandwidth, and expected job completion time, to compute R_{D_i}, as given in Equation 1.

$$R_{D_i} = \alpha_1 \frac{J_{deadline}}{J_{ECT}} + \alpha_2 \frac{POW_{avail}}{POW_{required}} + \alpha_3 \frac{M_{avail}}{M_{required}} + \alpha_4 \frac{B_{avail}}{B_{required}} \tag{1}$$

Where $J_{deadline}$ is the job deadline defined by a user; J_{ECT} is expected completion time of a job J; POW_{avail}, M_{avail}, and B_{avail} represent current availability of battery power, memory and bandwidth, respectively; $POW_{required}$, $M_{required}$, and $B_{required}$, represent the required power, memory and bandwidth, respectively, for job execution. $\alpha_1, \alpha_2, \alpha_3$ and α_4 are the weights associated with each parameter to indicate importance in job scheduling. Depending on the type of grid application (compute intensive/ data intensive/bandwidth intensive) the weights can be adjusted such that $\sum_{i=1}^{4} \alpha_i = 1$. We consider execution of compute intensive tasks, which depend heavily on processor speed (and lightly on other parameters) and assign more weightage to α_1. We assume that $J_{deadline} >= J_{ECT}$ and also, $POW_{required}$, $M_{required}$ and $B_{required}$ are given.

3.2 Economic Model

Economic (market) model enables resource sharing by offering resources at satisfiable cost to grid users. The non-cooperative bargaining game is used to design an economic scheme for negotiating resource cost and bandwidth. It suits well for negotiation in a wireless grid, where resource provider (p) and consumer (c) have potentially conflicting interests. This section describes parameters and rules, utility functions of c and p, counteroffers, and negotiation status in a non-cooperative bargaining game.

3.2.1 Game Parameters and Rules

The parameters associated with c and p that affect the bargaining game are concisely given in Table 1. Here, x represents either a player c or p. For c, the reserve price (RP_c) represents the maximum buying price of a resource and the reserve bandwidth (RB_c) represents the minimum bandwidth demanded for a job execution. Similarly, for p, the

Table 1. Game parameters of a player x (c or p)

Parameters	Meaning of Symbols
RP_x	Reserve price of a player x
MP_x	Market price of a player x. It is considered based on the history (statistics) of recent bargaining games it has participated
$P_x^{MP_x}$	Perceived probability of a player x that an opponent will accept MP_x
OP_x	Offered price of a player x, that maximizes the utility of its counteroffer
$P_x^{OP_x}(acc)$	Perceived probability of a player x that an opponent will accept OP_x
OP_{x_y}	Expected counter offered price of a player x predicted by the opponent y
$P_x^{OP_x}(rco)$	Perceived probability of a player x that an opponent will reject OP_x and counteroffer
$P_x^{OP_x}(rbd)$	Perceived probability of a player x that an opponent will reject OP_x and breakdown
RB_x	Reserve bandwidth of a player x
BW_x	Bandwidth offered/demanded by a player x
BW_{x_y}	Expected counter offered bandwidth of a player x predicted by the opponent y
MB_x	Market bandwidth of a player x. It is considered based on the history (statistics) of recent bargaining games it has participated
$P_x^{MB_x}$	Probability that a player x accepts MB_x
$P_x^{(OP_x,BW_x)}(acc)$	Perceived probability of a player x that an opponent will accept (OP_x, BW_x)
$P_x^{(OP_x,BW_x)}(rco)$	Perceived probability of a x that an opponent will reject (OP_x, BW_x) and counteroffer
$P_x^{(OP_x,BW_x)}(rbd)$	Perceived probability of a x that an opponent will reject (OP_x, BW_x) and breakdown
D_x^{bt}	Discount factor of a player x using discount strategy bt
CP_x	Counteroffer (counter proposal) of a player x
NS_x	Negotiation status of a player x
T_x	Time deadline of a player x to acquire/offer resource
U_x	Surplus (utility) of a player x

reserve price (RP_p) represents the minimum selling price of a resource and the reserve bandwidth (RB_p) represents the maximum bandwidth offered for a job execution. This indicates a conflict of interest of both players. They play a non-cooperative bargaining game and finally reach a mutual beneficial agreement to maximize their surplus.

The bargaining game between c and p is characterized by three rules described below.

Rule 1: at each step, both players choose an alternate offer that earns them highest expected surplus (U). For c,

$$U_c = [(RP_c - OP_c) + (BW_c - RB_c)] \times P_c^{(OP_c,BW_c)}(acc)$$

The surplus obtained indicates the gain in terms of the resource price and bandwidth.

On the other hand, for p,

$$U_p = [(OP_p - RP_p) + (RB_p - BW_p)] \times P_p^{(OP_p,BW_p)}(acc)$$

Rule 2: on rejection of an offer, c and p reduce the value of $P_x^{(OP_x,BW_x)}(acc)$ based on available resources and time deadline. This value decreases as the players come closer to their reserve values of price and bandwidth.

Rule 3: the demands of both c and p are decreased over the time. To depict this, we model a discount factor D_x^{bt} of both negotiators as described in next subsection based on the market situation. Here x represents a player ($x \epsilon \{c, p\}$) and bt represents a discount strategy. Modeling of D_x^{bt} helps converge the negotiation process faster.

Thus, for c,

$$U_c = [(RP_c - OP_c) + (BW_c - RB_c)] \times P_c^{(OP_c,BW_c)}(acc) \times D_p^{bt}.$$

On the other hand, for p,

$$U_p = [(OP_p - RP_p) + (RB_p - BW_p)] \times P_p^{(OP_p,BW_p)}(acc) \times D_c^{bt}$$

3.2.2 Utility of c

All the probabilities are predicted by c based on p's next possible action depending on the game state. Various actions of c against p's offer may include Accept, Breakdown, or Counteroffer represented as Acc, Bre, or Cou, respectively. Each offer contains a tuple (offered price, offered bandwidth), which contribute to the surplus.

1. If c accepts the current offer, its surplus is given by,

$$U(Acc_c) = [(RP_c - OP_p) + (MP_c - OP_p)] - [(RB_c - BW_p) - (MB_c - BW_p)] \qquad (2)$$

The term $(MP_c - OP_p)$ indicates the penalty from the market if the offered price by p is accepted by the bargaining game. The BW_p increases with time, resulting in increase in the surplus of c. The gain in surplus due to bandwidth follows the same rules as those for the offered price.

2. If c rejects the offer of p and breaks down from the game, then its surplus is given by,

$$U(Bre_c) = (RP_c - MP_c) \times P_c^{MP_c} - (RB_c - MB_c) \times P_c^{MB_c} \qquad (3)$$

The second term indicates the potential loss of surplus from the market in terms of bandwidth contributed to jobs.

3. If c counteroffers, then its surplus depends upon the following factors: (i) surplus obtained if p accepts the current offer of c, (ii) surplus obtained if p rejects the offer of c and breaks down from the game, and (iii) surplus obtained if p rejects the counter offer of c and proposes another offer from its end. Thus,

$$\begin{aligned} U(Cou_c) \quad = \quad & [[(RP_c - OP_c) + (MP_c - OP_c) - (RB_c - BW_c) - (MB_c - BW_c)] \times P_c^{(OP_c,BW_c)}(acc) \\ & +[U(Bre_c) \times P_c^{(OP_c,BW_c)}(rbd)] + [(RP_c - OP_{p_c} - RB_c + BW_{p_c}) \times P_c^{(OP_c,BW_c)}(rco)]] \\ & \times D_c^{bt} \end{aligned} \qquad (4)$$

It should be noted that $P_c^{(OP_c,BW_c)}(acc) + P_c^{(OP_c,BW_c)}(rbd) + P_c^{(OP_c,BW_c)}(rco) = 1.$

3.2.3 Utility of p

All the probabilities herein are predicted by the provider node based on the c's next possible action. Various actions of p against c's offer may include Accept, Breakdown, or Counteroffer. The calculations are similar to the c's utility functions and are given by Equations (5), (6) and (7).

$$U(Acc_p) = [(OP_c - RP_p) + (OP_c - MP_p)] - [(BW_c - RB_p) - (BW_c - MB_p)] \qquad (5)$$

$$U(Bre_p) = (MP_p - RP_p) \times P_p^{MP_p} - (MB_p - RB_p) \times P_p^{MB_p} \qquad (6)$$

$$\begin{aligned} U(Cou_p) \quad = \quad & [[(OP_p - RP_p) + (OP_p - MP_p) - (BW_p - RB_p) - (BW_p - MB_p)] \times P_p^{(OP_p,BW_p)}(acc) \\ & + U(Bre_p) \times P_p^{(OP_p,BW_p)}(rbd)] + [(OP_{c_p} - RP_p - BW_{c_p} + RB_p) \times P_p^{(OP_p,BW_p)}(rco)]] \\ & \times D_p^{bt} \end{aligned} \quad (7)$$

3.2.4 Counteroffer Model

The counteroffer or counter proposal (CP) consisting of two negotiation parameters such as offered price and offered bandwidth is modelled considering dynamics in the grid market as follows.

For consumer c, a time-dependent CP, at time t is given by Equation 8

$$CP_c[t] = ([OP_c[0] + (\frac{t}{T_c})^{\beta}(RP_c - OP_c[0])],\ [BW_c[0] - (\frac{t}{T_c})^{\beta}(BW_c[0] - RB_c)]) \quad (8)$$

where the terms $(\frac{t}{T_c})^{\beta}(RP_c - OP_c[0])$ and $(\frac{t}{T_c})^{\beta}(BW_c[0] - RB_c)$ represent the discounts offered by c with respect to the resource price and bandwidth; $OP_c[0]$ is the initial offered price; T_c is the c's deadline to acquire resources; t denotes the current time instant in the negotiation time; β ($\beta > 0$) value determines the discounting pace with the time. There are three typical strategies that are adopted by changing the value of β. (1) $\beta > 1$, conservative strategy (where c maintains the initial price until the deadline is almost reached); (2) $0 < \beta < 1$, aggressive strategy (where c concedes rapidly to the reserve price); and (3) $\beta = 1$, linear strategy (where c concedes linearly). These three strategies are used to support convergence of bargaining process as early as possible.

To generate counteroffers, the bargaining process adapts according to market dynamics by considering the parameters such as the number of p's (or N_p) and failure to success ratio (FSR). FSR is defined as the ratio of number of times the user has failed to obtain required grid resources to the number of times he/she succeeded. This information is obtained based on the history of user's previous interactions. That is, if the N_p is more and/or FSR is very less, then c will negotiate by increasing discount slowly, otherwise the discount is increased rapidly. Hence a market dynamics and time-dependent counteroffer consisting of parameters such as offered price and bandwidth, is computed as given by the Equation 9.

$$CP_c[t] = ([OP_c[0] + (\frac{t}{T_c})^{\beta}(RP_c - OP_c[0]) \times \frac{FSR}{N_p}],\ [BW_c[0] - (\frac{t}{T_c})^{\beta}(BW_c[0] - RB_c) \times \frac{FSR}{N_p}]) \quad (9)$$

For provider p, a time-dependent counteroffer CP at time t is obtained similar to c as given by,

$$CP_p[t] = ([OP_p[0] - (\frac{t}{T_p})^{\beta}(OP_p[0] - RP_p)],\ [BW_p[0] + (\frac{t}{T_p})^{\beta}(RB_p - BW_p[0])]) \quad (10)$$

It considers market dynamics such as the resource demand (d) and number of user's previous interactions (N_{ui}) while generating counteroffers. If the resource demand from users is more, and/or the number of user interactions is less, then p proposes by increasing discount slowly and vice versa. Hence a market dynamics and time-dependent counteroffer is computed as given by the Equation 11.

$$CP_p[t] = ([OP_p[0] - (\frac{t}{T_p})^{\beta}(OP_p[0] - RP_p) \times \frac{N_{ui}}{d}],\ [BW_p[0] + (\frac{t}{T_p})^{\beta}(RB_p - BW_p[0]) \times \frac{N_{ui}}{d}]) \quad (11)$$

3.2.5 Negotiation Status Model

Each player determines his/her negotiation status in the current grid market based on the counter proposals of an opponent. For example, the *negotiation status of c* at negotiation time t, $NS_c(t)$ is determined as follows: If p is offering larger discounts, then $NS_c(t)$ is favorable (ie. c can negotiate relatively more). If p is offering smaller discounts, then $NS_c(t)$ is unfavorable (ie. c can negotiate relatively less). If p is offering discounts linearly, then $NS_c(t)$ is balanced (ie. c can negotiate linearly).

Let $\delta_p^i(t)$ be the difference between counter proposals in the previous and current offer and $\Delta_p^i(t)$ be the difference between proposals in the initial and current offer of i^{th} provider as given in Equations 12 and 13, respectively.

$$\delta_p^i(t) = CP_p^i[t-1] - CP_p^i[t] \tag{12}$$

$$\Delta_p^i(t) = CP_p^i[0] - CP_p^i[t] \tag{13}$$

Then $NS_c(t)$ can be defined as the ratio of discount in the current negotiation $\delta_p^i(t)$ to an average amount of discount in the previous t negotiations $\Delta_p^i(t)/t$ as given in Equation 14.

$$NS_c(t) = \frac{\delta_p^i(t)}{\left(\frac{\Delta_p^i(t)}{t}\right)} \tag{14}$$

If $NS_c(t) >> 1$, then a consumer is in favorable and advantageous market at time t, since providers are giving larger discounts. If $NS_c(t) << 1$, then a consumer is in unfavorable and disadvantageous market since providers are offering small discounts. If $NS_c(t) = 1$, then a consumer is in balanced and neutral market since providers are giving linear discounts.

Similarly, the *negotiation status of provider*, $NS_p(t)$, can be computed by observing the discount patterns of the consumer. Based on the dynamically derived negotiation status, each player decides to apply either aggressive or conservative or linear bargaining strategy to generate counteroffers such that the negotiation process converges fast.

4 Multiagent Approach for Seamless Job Scheduling

This section describes the proposed architecture, agencies and algorithm for seamless job scheduling.

4.1 Architecture

Figure 2 shows a high-level architecture of the proposed scheme. It includes P number of UAs (user agents) representing consumers, Q number of RBs representing resource brokers, and R number of PAs (provider agents) representing resource providers. We consider many-to-many relationship between UAs and RBs because each UA can request multiple RBs and each RB can receive requests from multiple UAs for job execution. One-to-many relationship between RB and PAs is considered, because the selected RB plays a non-cooperative bargaining game with chosen reliable PAs.

UA submits user's grid (parallel) job to RB with requirement specifications such as maximum affordable price (reserve price), minimum required bandwidth (reserve bandwidth), job deadline, number of processors, memory and storage. We consider that RB decomposes

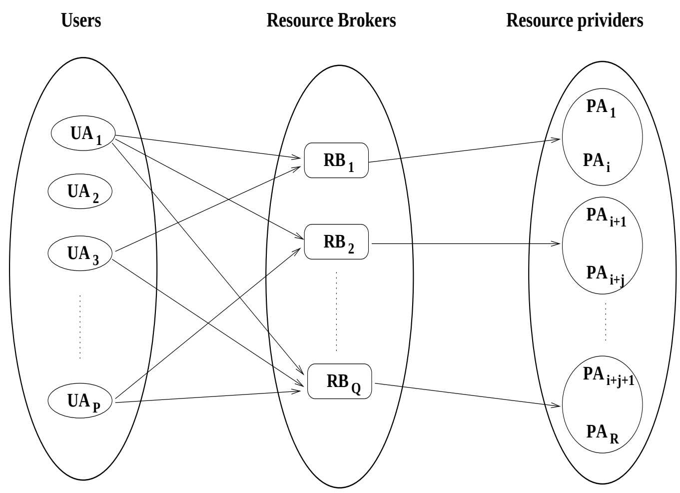

Figure 2. Architecture of seamless job scheduling scheme

each job into sj number of independent subjobs of equal size and distributes each subjob to reliable device after negotiating the price and bandwidth. RB plays bargaining game on behalf of UA with sj PAs.

4.2 Agencies

The proposed seamless job scheduling scheme consists of two agencies: GIS agency and RB agency. These agencies are described as follows.

4.2.1 GIS Agency

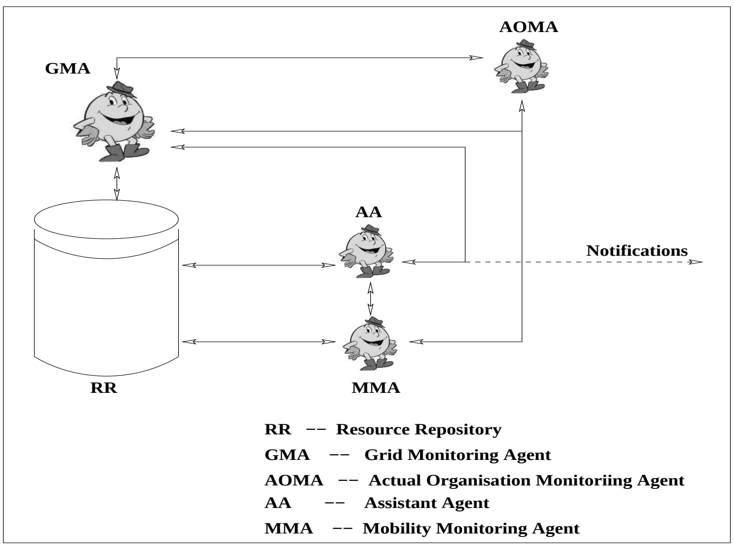

Figure 3. GIS Agency

The GIS agency shown in figure 3 consists of a RR and four agents: GMA, AOMA, AA, and MMA. These agents monitor the device status and mobility, control the device state such that it does not get overloaded, provide resource availability information, and try to maintain the overall grid health [27]. They are described as follows.

RR : the RR is a data store for all devices. It provides the information of different wireless devices along with the status of their static and dynamic resources, observed at a particular time-stamp. Static resources may include processor type, RAM, OS, etc., whereas dynamic resources may include processor utilisation, free memory, free disk space, battery power, bandwidth, signal strength, etc.

GMA : the GMA collects the status information of all devices along with bandwidth availability and stores in RR. It is responsible for providing the resource availability information of overall grid.

AA : the AA controls the state of a device such that it does not get overloaded. Based on the current status, it applies optimality principle to suggest certain relevant actions to control the device state.

AOMA : the AOMA keeps track of all wireless devices available in the grid. It monitors the joining/leaving of each device into/from grid. When device enters a cell, it has to register with AOMA by providing its resource details. After the registration, the device status will be monitored by GMA, and its mobility will be monitored by MMA. When the device is moving out of the grid, MMA notifies AOMA to deregister it. Then, GMA removes all details associated with such device from RR.

MMA : the MMA keeps track of location of each device which is helpful to decide whether the device can be considered for job scheduling. MMA employs a normal walk mobility model [28] for cellular network to monitor the device mobility. The normal walk mobility model represents the daily mobility patterns of a wireless device and the direction of motion in a real life environment. When a device is moving from one BSC to another, the normal walk model finds the direction in which it is moving. Based on its direction of movement, MMA predicts the possible BSCs for executing handoff procedures (in advance). Here, a device can move out of local cell and enter into any of the surrounding six cells. If we consider C as set of cells, D as set of devices, and $P_{d,i,j}(\mathrm{t})$ as the probability of a device d moving from i^{th} to j^{th} cell during time interval t, then we have

$$\sum_{j=1}^{6} P_{d,i,j}(t) = 1$$

such that $d \epsilon D$, $\{i,j\} \epsilon C$.

4.2.2 RB Agency

The RB agency shown in figure 4 consists of three agents: JAA, MA, and NA. These agents are responsible for discovering reliable devices, negotiating resource cost and bandwidth, and seamless scheduling of jobs by interacting with agents of GIS agency.

JAA : user agent submits a user job to RB agency for scheduling. RB agency decomposes the user job into sj number of subjobs of equal size, and requests MA to discover sj number of most reliable devices for allocation. Then, it requests NA to play a non-cooperative bargaining game with the sj devices to negotiate a resource cost and bandwidth. Once negotiation is completed, JAA maps subjobs to chosen reliable devices on first come first serve order. During execution of a subjob, if any of the device moves out of the control of RB agency, then JAA dynamically decides whether to resume subjob execution on the same device or terminate and reschedule to some other reliable device. If a device moves

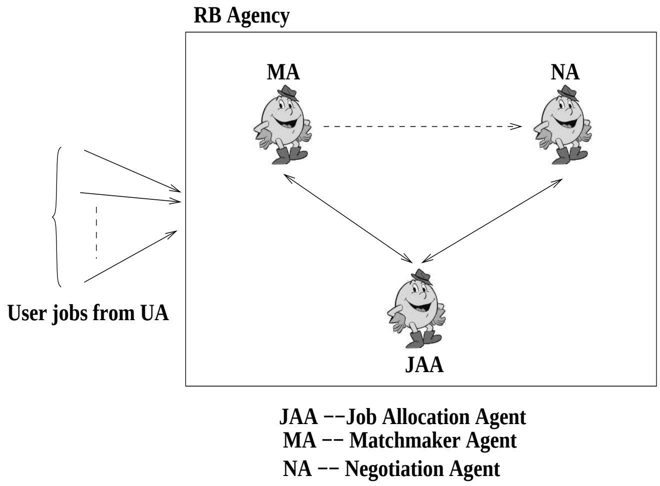

Figure 4. RB agency

out and enters into range of another BSC belonging to a local MSC, then it continues execution, otherwise it terminates the job and reschedules to other reliable device for successful completion of job execution.
MA : MA discovers reliable devices (PAs) which can be used for allocation. MA interacts with GIS agency to obtain the statistical status information of each device, and computes the reliability of each device using equation 1. MA sorts devices in descending order of their reliability and recommends sj number of high reliable devices for allocation.
NA : the NA plays a non-cooperative bargaining game concurrently with sj number of reliable PAs to negotiate a resource cost and bandwidth. Each one tries to optimize his/her surplus. Keeping in mind the reserve values of price and bandwidth, NA begins bargaining with minimum price and maximum bandwidth, whereas PA begins with maximum price and minimum bandwidth.

During bargaining, at some point, both of them will agree upon a resource price and bandwidth, and converge the negotiation process. To support the convergence of negotiation as early as possible, both NA and PA observe their negotiation status in the current market and adapt themselves to apply either conservative or aggressive or linear discount making strategy.

4.3 Algorithm

Algorithm 1 presents an overview of a seamless job scheduling scheme. It is a four stage process: (1) MA discovers reliable devices, (2) NA plays a concurrent non-cooperative bargaining game to negotiate resource cost and bandwidth, (3) JAA schedules jobs to reliable devices, and (4) during execution, if any device moves out from local MSC to some other MSC range, JAA terminates the job and dynamically reschedules to some other reliable device for seamless execution.

5 Simulation

The proposed scheme is simulated using C# Programming language. This section describes the simulation model, performance parameters and simulation procedure.

Algorithm 1 Seamless job scheduling

1: *Input :* Grid (parallelizable) job with requirement specifications.
2: *Output :* Seamless job scheduling to reliable and cost optimal devices in a bandwidth constrained environment.
3: UA submits job to RB agency.
4: JAA decomposes job into sj subjobs.
5: MA computes reliability of each device (by interacting with GMA) using equation 1 and recommends sj reliable devices (PAs) for scheduling.
6: NA plays a concurrent non-cooperative bargaining game with these sj PAs to negotiate resource cost and bandwidth,
   - Each player observes its negotiation status (see section 3.2.5) to see whether the market is favorable or not, and applies either aggressive, or conservative, or linear discount strategy accordingly,
   - Counteroffer of each player for subsequent rounds is generated dynamically considering grid market dynamics (see section 3.2.4).
7: JAA schedules sj subjobs to these PAs.
8: PAs start execution of received subjobs.
9: During execution
10: **if** JAA observes (by interacting with MMA) that PA is either not moving, or moving within same cell, or moving across cell but within same BSC **then**
11:    it informs PA to continue execution.
12: **else**
13:    **if** JAA observes that the PA is leaving local BSC and entering into another BSC, but of same MSC **then**
14:       Local GMA interacts with GMA of new BSC to check whether negotiated amount of bandwidth is available.
15:       **if** bandwidth is available **then**
16:          GMA informs JMA about bandwidth availability.
17:          Handoff procedure is executed between BSCs.
18:          JAA informs PA to continue execution.
19:       **else**
20:          goto 24.
21:       **end if**
22:    **else**
23:       **if** JAA observes that the PA is entering into BSC of another MSC **then**
24:          JAA terminates subjob scheduled to it.
25:          JAA obtains information of another (next) PA from MA.
26:          JAA obtains information of negotiated cost and bandwidth from NA.
27:          JAA reschedules subjob to that PA.
28:       **end if**
29:    **end if**
30: **end if**

5.1 Simulation Model

The simulated grid environment of the proposed work consists of four models: grid model, consumer model, provider model and an agent model. The models are presented as follows.

Grid model: A cellular communication network based wireless grid environment is considered. A wireless grid consists of a number of MSCs and b number of BSCs. Each BSC controls c number of BTSs (cells), and each cell is comprised of m number of wireless devices distributed randomly. $T_{transmitJ}$ is the job distribution time and $T_{transmitR}$ is the result collection time.

Reliability model: Wireless devices are characterized by configuration parameters such as S processor speed, μ processing rate, POW battery power, M memory and B transmission bandwidth. $\alpha_1, \alpha_2, \alpha_3$ and α_4 are the weights associated with processor, battery, memory and bandwidth respectively, to indicate their importance to a grid application.

Consumer model: j number of grid (parallelizable) jobs with a mean interarrival time of ar milliseconds are generated using uniform random distribution. Each job is divided into sj number of equal size subjobs. Consumer model has some other simulation parameters such as job deadline ($J_{deadline}$), reserve price (RP_{NA}), reserve bandwidth (RB_{NA}), maximum number of negotiations (N_{negmax}), number of providers (N_p) and failure to success rate (FSR).

Provider model: It consists of m number of devices with configuration parameters as mentioned in the reliability model. Highly reliable sj number of PAs play bargaining game with NA. Provider model has some other simulation parameters such as reserve price (RP_{PA}), reserve bandwidth (RB_{NA}), number of user interactions (N_{ui}) and demand for resource (d).

The values of c, m, RP_{NA}, RP_{PA}, RB_{NA}, RB_{PA}, MP_{NA}, MP_{PA}, MB_{NA}, MB_{PA}, N_p, FSR, N_{ui}, d, S, μ, POW, M, B, $T_{transmitJ}$ and $T_{transmitR}$ are assumed to be randomly distributed within a range. The values of perceived probabilities that an offer will be either accepted, or rejected and counteroffer, or rejected and breakdown, are guessed by a bargainer depending on opponent's reactions.

Based on above mentioned simulation model, the Table 2 shows simulation inputs.

5.2 Simulation Results

The proposed seamless job scheduling scheme is simulated to evaluate its performance with respect to performance parameters such as the surplus, job completion time, and job execution rate. The simulation results are discussed as follows.

Analysis of Surplus

In the negotiation process between PA and NA; for PA, the offered price decreases and the offered bandwidth increases, whereas for NA, the offered price increases and the offered bandwidth decreases. The surplus of both PA and NA reduces with the increasing negotiation time and the offered values of resource price and bandwidth. Figure 5 shows the surplus of PA against different values of offered price and bandwidth for two negotiations. Observe that, with time, PA reduces offered price and increases offered bandwidth by values of axes *offered price* and *offered bandwidth* (from Left to Right). Each surplus value indicates a gain obtained from the corresponding tuple (offered price, offered bandwidth). The surplus is maximum in the beginning of bargaining game and decreases with the

Table 2. Simulation inputs

Notation	Name	Value
a	Number of MSCs	1
b	Number of BSCs	2
c	Number of BTSs	[2 - 4]
m	Number of devices	[20 - 100]
α_1	Weightage of processor	0.5
α_2	Weightage of battery	0.2
α_3	Weightage of memory	0.1
α_4	Weightage of bandwidth	0.2
j	Number of jobs	[20 - 100]
sj	Number of subjobs	3
ar	Job interarrival time	100
$J_{deadline}$	Job deadline	50
RP_{NA}, RP_{PA}	Reserve price of NA, PA	[60 - 80]
MP_{NA}, MP_{PA}	Market price of NA, PA	[40 - 100]
RB_{NA}, RB_{PA}	Reserve bandwidth of NA, PA	[200 - 400]
MB_{NA}, MB_{PA}	Market bandwidth of NA, PA	[100 - 500]
N_{negmax}	Max. number of negotiations	10
N_p	Number of resource providers	[10 - 30]
FSR	Failure to success ratio	[0.1 - 1.2]
N_{ui}	Number of user interactions	[4 - 10]
d	Resource demand	[10 - 30]
S	Processor speed	[200 MHz - 1.2 GHz]
μ	Processing rate	[1 jobs/sec - 7 jobs/sec]
POW	Battery power	[0 VAh - 100 VAh]
M	Memory	[64 MB - 1 GB]
B	Transmission bandwidth	[100 Kbps - 1 Mbps]
$T_{transmitJ}$	Job distribution time	[0.01 sec - 0.15 sec]
$T_{transmitR}$	Result collection time	[0.01 sec - 0.12 sec]

negotiation time. This is because, during the negotiation process PA keeps on decreasing the offered price and increasing the offered bandwidth in each of its counteroffer.

Similarly, with time, NA increases offered price and decreases bandwidth by values of axes *offered price* and *offered bandwidth* (from Right to Left) as shown in Figure 6. The surplus is maximum in the beginning of bargaining game and decreases with the negotiation time. This is because, during the negotiation process NA keeps on increasing the offered price and decreasing the offered bandwith in each of its counteroffer.

Analysis of Job Completion Time

Job completion time (JCT) is defined as the sum of transmission, waiting, and processing time of a job. It can be reduced by choosing reliable devices and speeding up the negotiation process. Figure 7 represents the average JCT of subjobs considering different number of devices. Considering 30 devices, the JCT of proposed work matches with that of [21] (marked as Ghosh in the graphs) upto some number of subjobs (150). But the further

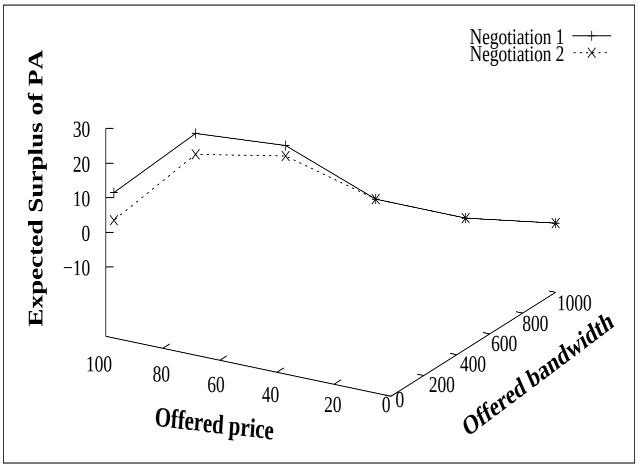

Figure 5. Expected Surplus of PA Vs. Offered price and bandwidth

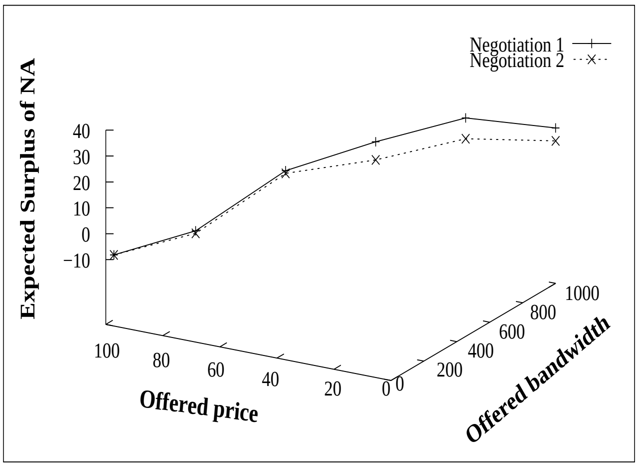

Figure 6. Expected Surplus of NA Vs. Offered price and bandwidth

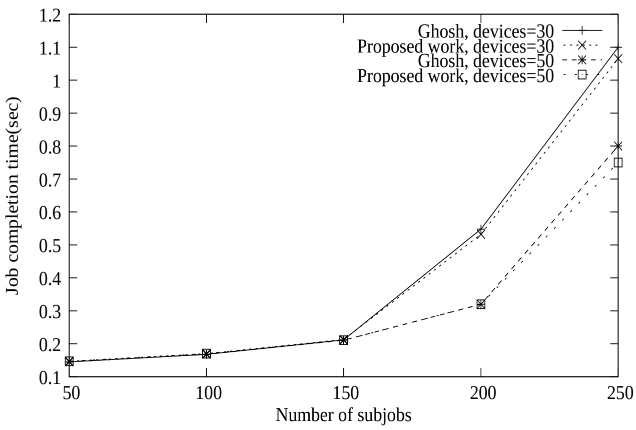

Figure 7. Job Completion Time Vs. Number of subjobs

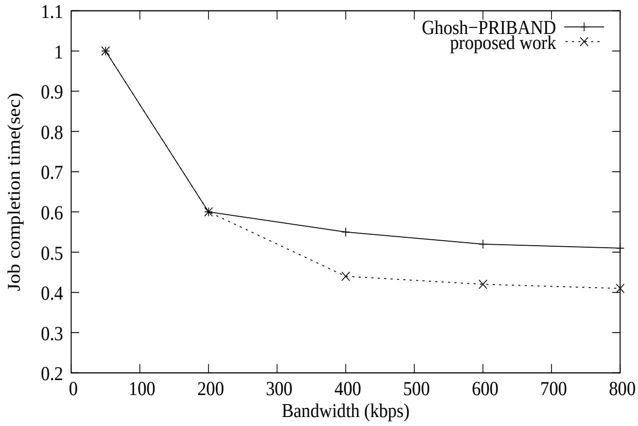

Figure 8. Job Completion Time Vs. Bandwidth

increase in number of subjobs results in considerable decrease of JCT. Even though proposed work needs some extra time to discover and recommend reliable devices (which is not considered in [21]), JCT matches with that of [21] because of its speedy negotiation process and seamless scheduling of jobs to reliable devices. We observe decrease in JCT for 50 devices as compared to 30 devices after 150 number of subjobs.

Assuming that all PAs have the same bandwidth, figure 8 shows the JCT of the PRIBAND (PRIce-based scheme for BANDwidth constrained environment) algorithm of [21] and the proposed work. For both cases, the JCT is more in presence of lesser bandwidth. It decreases rapidly with the bandwidth 50 to 300 kbps, and beyond that it decreases slowly. However, we observe that the JCT of proposed work is lesser than that of [21] in presence of more bandwidth. It is because, the communication (transmission) and negotiation delays become negligible in presence of more bandwidth and only the processing delay contributes much to JCT. JCT is decreased due to consideration of reliable devices (whose processing rate is more) for allocation.

The mobility factor (MF) represents the percentage of devices that are roaming. The JCT is affected by both the number of subjobs (system load) and the MF as observed in figure 9. With 20% of MF, the JCT increases slowly upto some number of subjobs (200). But the sudden increase of JCT after this point is mainly because of the system load. Similarly, with 40% of MF, the JCT increases fast initally upto some number of subjobs and later slowly, because of both the MF and the system load.

In the figure 10, with 20% of MF, the JCT decreases faster upto some bandwidth (400 kbps), and afterwards there is no further decrease. Similarly, with 40% of MF, the JCT decreases faster only upto some bandwidth (600 kbps). It is because the communication and negotiation delays become negligible and processing delay carries more weightage with higher availability of bandwidth. However if the MF value is more, the higher availability of bandwidth has its impact on decreasing the JCT.

Analysis of Job Execution Rate

Job execution rate (JER) is defined as the percentage of the ratio of total number of jobs executed successfully to the total number of jobs submitted to the grid in a given time interval. Figure 11 shows the slow decrease of the JER with the increase in number of subjobs. Even though the mobility and a load of a device has diverse impact on successful

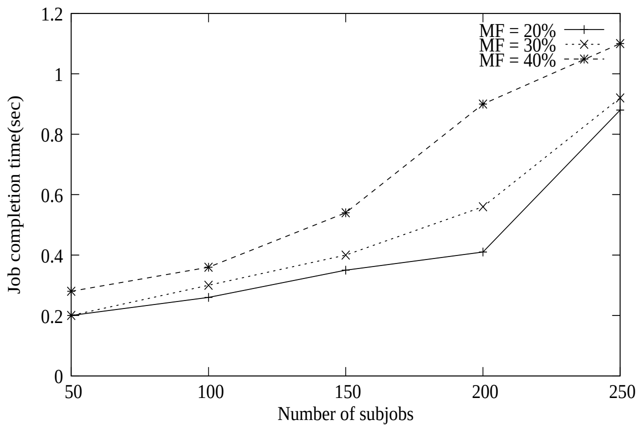

Figure 9. Job Completion Time Vs. Number of subjobs (for different MFs)

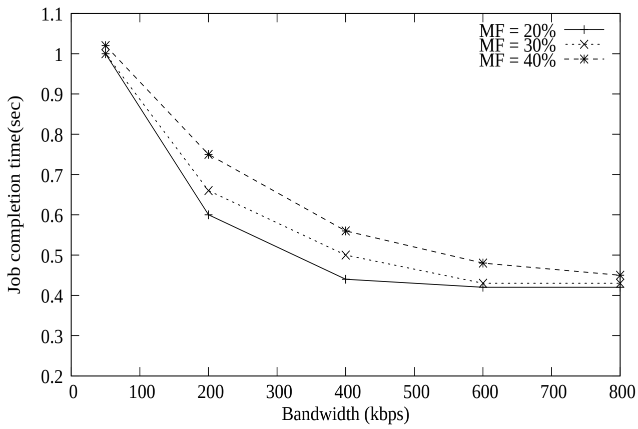

Figure 10. Job Completion Time Vs. Bandwidth (for different MFs)

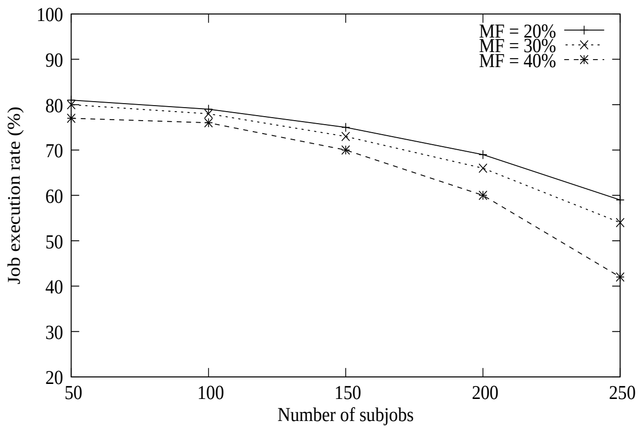

Figure 11. Job execution rate Vs. Number of jobs

execution of a job, the proposed scheme maintains certain JER (43%). It is due to reliable devices chosen for scheduling.

6 Conclusions

This paper proposed an economic scheme for seamless job scheduling in bandwidth constrained wireless grids using multiagent architecture. The scheme is scalable, flexible and adaptable: it keeps track of device mobility and scales to accomodate entering/leaving devices in the grid; during device mobility, it is flexible in deciding whether the job scheduled should continue or terminate its execution and reschedule to another reliable device for successful completion; based on market dynamics and player's bargaining status, it adapts negotiation process by generating counteroffers (on bandwidth and cost) that converge fast.

The scheme consists of two agencies: GIS and RB agency. The GIS agency maintains the detailed information of overall grid infrastructure and provides resource availability information to the RB agency. The RB agency discovers and recommends reliable devices which are allocated after the negotiation of resource cost and bandwidth. During job execution, if a device moves out to some other MSC, then RB agency dynamically reschedules its job to other local reliable device for its seamless execution. The scheme is simulated to evaluate the performance parameters such as surplus, job completion time and job execution rate. The results show that the proposed scheme is better than existing job allocation scheme in terms of the job completion time.

However, the proposed work has following limitations which can be addressed in the future works: (1) the scheme may be extended to consider variable size subjobs execution, (2) the device reliability model can be modified to include device mobility, and (3) scheduling mechanism can be extended to support the device mobility in any MSC.

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