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Development of Birth-Death update rule using Evolutionary Game Theory for Self-Organized Data Aggregation Technique in Delay Tolerant Network (DTN)

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List of Acronyms

DTN	Delay Tolerant Network
GT	Game Theory
EGT	Evolutionary Game Theory
IM	Imitation
BD	Birth-Death
MANET	Mobile ad-hoc networks
UAV	Unmanned aerial vehicle
OPWP	Optimized Way-points
TCP	Transmission Control Protocol
DARPA	Defense Advanced Research Projects Agency
ADU	Application-defined data unit
ESS	Evolutionarily Stable Strategy
IP	Internet protocol
ESS	Evolutionary Stable Strategy
OPWP	Optimized Way Points
NASA	Defense Advanced Research Projects Agency

Abstract

Delay Tolerant Networks (DTN) can provide data connectivity for areas where internet cannot provide any end to end connectivity. In DTNs, store-carry-forward mechanism with the help of custody transfer technique provides reliable end-to-end data transfer where nodes which transfer data with custody called custodians. In this system, sometimes storage congestion may occur. This drawback can be improved by using special mobile nodes called message ferries. In such scenario, it is better to aggregate data to some custodians so that the message ferry can efficiently collect them and carries collected bundles to a base station referred to as a sink node. When there are several isolated clusters (formed by physically close wirelessly connected nodes), message ferry have to visit those clusters and collects bundles from custodians. When message ferry visits any individual cluster (referred to as intra-cluster visit or visit within cluster), sometimes it is not possible to visit and collect data from all nodes in that cluster within particular period of time. To resolve this problem, self-organized data aggregation technique is developed, where, with the help of the evolutionary game theoretic approach, the system can automatically select some limited number of nodes (custodians) called aggregators. As a result, the message ferry visits and collects bundles only from those aggregators in that particular cluster. In this technique, Aggregators are changed autonomously in each round. In self-organized data aggregation technique, the strategy (i.e., to become aggregator or sender) of selection of aggregators is modeled as a game in evolutionary game theory, where, each node will draw payoff after interaction. For strategy selection, Imitation Update Rule of evolutionary game theory was used previously. In this research, we developed the replicator equation, agent based dynamics of a novel update mechanism called **Birth-Death Update Rule** and simulated the agent based dynamics in Netlogo software. The simulation outcome shows that number of alive nodes increase with time, quick convergence of the game to equilibrium and finally higher probability of nodes with more degree to be aggregator.

Chapter 1

Introduction

With the progress made in the field of networking technology, many researchers and developers have tried to achieve data communications in challenged networks, called delay tolerant networks (DTNs) [1], [2], like disaster areas, rural areas without infrastructure, deep space, battle field, sensor networking of distant regions etc. DTN is an approach to computer network architecture that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity. A DTN is a network of smaller networks. It is an overlay on top of special-purpose networks, including the Internet [3]. Examples of such networks are those operating in mobile or extreme terrestrial environments, or planned networks in space. Recently, the term disruption-tolerant networking has gained currency in the United States due to support from DARPA, which has funded many DTN projects [4]. Disruption may occur because of the limits of wireless radio range, sparsely of mobile nodes, energy resources, attack, and noise.

1.1 A look into the status quo of DTN structure

In DTNs, *custody data transfer* [5] mechanism is used. It deals reliable end-to-end data transfer in which *custodians* transfer data with custody. Custodians are the intermediate nodes which keep custody bundles. The custodians should have a huge space to hold the data custody until there is a successful data transfer. So to be a custodian, a node must reserve a sufficient amount of storage. Also custodians generate their own data .So space congestion may occur due to huge data. Due to space congestion, they refuse to take custody of other nodes. As every custodians also generate its own data, energy of battery decrement is a problem. It is selfish behavior of nodes to save their own battery life.

To solve this congestion problem some special mobile nodes can be introduced to proactively travel the network and gather bundles from the custodians before congestion occur. This is called message ferries.

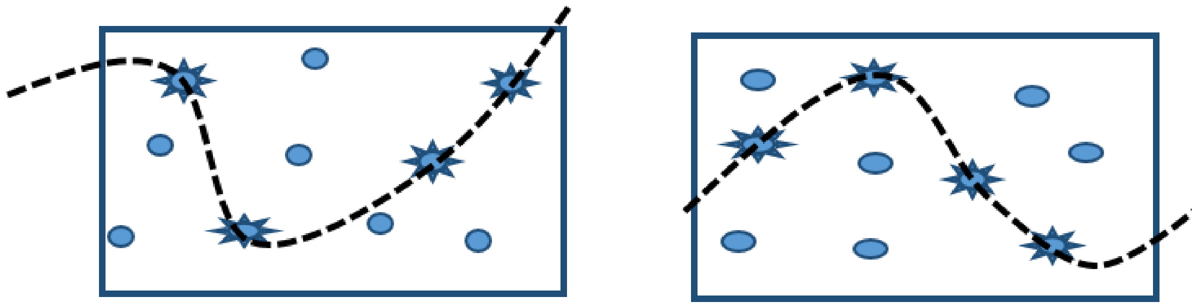
Message ferries [4] can solve the storage congestion problem by actively visiting the network and gather bundles from the custodians. Note that the message ferry has a sufficient amount of storages and energy to carry the bundles to the corresponding destination, i.e., a base station referred to as *sink node* [4], and it can also supply energy to the nodes if required. When there are several isolated networks referred to as *clusters*, the message ferry must visit each of the cluster and collects bundles from the custodians as shown in Fig.1.1. In such kind of scenarios, however, sometimes it is difficult for the message ferry to visit all of the nodes in a certain period of time. Taking account of the challenges, we developed an agent based dynamics of a self-organized data aggregation technique in [6]. With the help of the evolutionary game theoretic approach [7-9], our system can automatically select some special custodians referred to as *aggregator* , which are cooperative in nature and willingly hold custody bundles of other nodes referred to as *senders.*

Therefore, the message ferry [10] needs to collect the bundles only from the aggregators. Note here that in this scheme, each aggregator must keep awake to receive and hold the bundles until transferring them to the message ferry, while each sender awakes only when generating and sending the bundles. In addition, each aggregator can obtain energy supply from the message ferry only when it finds a sender as its neighbor. In our scheme, each node appropriately selects strategy, i.e., sending or aggregating, depending on neighbors' strategies. This interaction among nodes is modeled as a game in game theory. As clusters are formed by physically close wirelessly connected nodes, sometimes it is not possible for the message ferry to visit all the nodes in a cluster and collects data individually in a certain period of time. Taking amount of these challenges on mind, *self-organized data aggregation technique* [4] is developed. With the help of the evolutionary game theoretic approach , the system can automatically select some custodians referred to as *aggregators*, which are cooperative in nature and willing to hold custody bundles of other nodes referred to as senders. Therefore, message ferries need to collect the bundles only from the aggregators.

Each node is equipped with a long range radio and a short range radio [4]. While the message ferry approaching to the cluster it broadcasts its availability to all members of the cluster. Only aggregators with specific amount of bundles are allowed to transmit service request to the message ferry by their long range radio. These service request message contains: 1) information of all aggregators location.2) the amount of bundles it wants to transmit. To guide the message ferry, the aggregator occasionally transmit location update message on reception of each information, the message ferry calculate the intra cluster path. When the message ferry and one aggregator is close enough, the aggregator transfer bundles by it short range radio to the message ferry .At the same time, it get energy supply from the message ferry.

Initially each node randomly chosen to be an aggregator or a sender because it can't know the neighbors behavior. In the successfully rounds, each nodes selects their role depending on their results of the previous round with the help of Evolutionary Game theory. Due to lack of reliable connectivity among arbitrary nodes, it is difficult to achieve centralized controls in DTN.

Note here that in this scheme, each aggregator should keep awake to receive and hold bundles until transferring them to the message ferry, while each sender wakes up only when generating and sending bundles, as well as deciding its next role. In addition, each aggregator can obtain energy supply from a message ferry only when it finds a sender among its neighboring nodes. In our scheme, each node appropriately selects its strategy (i.e., being a sender or aggregator), depending on strategies of neighboring nodes. If both nodes are selected to be an aggregator, they lose largest energy without any energy supply from the message ferry because they are not able to collect sufficient number of bundles to request the message ferry to visit. At the initial time none of the cluster member have any bundles. While some cluster member generate their own bundles, they seek for aggregators



(a) (b)

Fig.1. 1 Role of aggregators are changing after each round. In figure (b), the aggregators have changed their roles than from figure (a)

within the transmission range. If no aggregator is available, the initial bundle generators become aggregators.

The aggregators are changed in each round [4] as shown in Fig.1.1 (The unit time at which the role of each node is changed) in decentralized way as per the requirement of energy [4]. The number of aggregator can be controlled by adjusting the energy that the message ferry supplies to the aggregators.

In self-organized data aggregation technique [4], the strategy (i.e., to become aggregator or sender) of selection of aggregators is modeled as a game in evolutionary game theory [11], where, each node will draw payoff after interaction. Our work is focused onto developing the algorithm for the "Birth-Death Update Rule" of selection of aggregators in a no-transmission scenario.

1.2 Literature review

Evolutionary game theory [7,8] provides us with both theoretical framework and simulation-based framework. The theoretical framework called replicator dynamics [7, 8, 9] is a mathematical model, where the ratio of individuals selecting a strategy increases when the strategy can yield more payoff [4] than the average payoff of the whole system .The replicator dynamics [12, 7, 8] is applicable when the population composed of the society is relatively large and well mixed. In actual situations, however, the interactions among individuals are restricted: Each individual knows only a small fraction of members in the society.

To overcome this drawback, Ohtsuki et al. proposed replicator dynamics on graphs by introducing the concept of topological structure into replicator dynamics .They derived replicator dynamics on graphs for three kinds of strategy-updating rules: Birth-death updating, death-birth updating, and imitation updating.

K. Kabir et. al., in 2011, proposed an algorithm for determining the optimal visiting order of isolated static clusters in DTNs [13]. In 2012, K. Kabir et. al. aimed to make groups each of which consists of physically close clusters, a sink node, and a message ferry, in order to minimize the overall mean delivery delay of data bundles [14]. They developed simple heuristic algorithms and through simulation experiments showed that the optimal solution can be obtained by appropriate parameter setting, when the clusters are randomly distributed over the area. In 2009, K. Kabir et. al. proposed a scheme to aggregate data into selected custodians, called aggregators, in a fully distributed and autonomous manner by using evolutionary game theoretical approach where they could also control the number of aggregators to a desired value [6]. In 2010, K. Kabir et. al. proposed a scheme to aggregate data into selected custodians, called aggregators, in a fully distributed and autonomous manner with the help of evolutionary game theoretic approach [4]. In 2010, they further examined the proposed system in terms of success of data transmission and system survivability [4]. In 2013, they even further examined the proposed system in terms of successful data transmission, system survivability and the optimality of aggregator selection [13]. They also first introduced a new game model with retransmission scenerio. K. Habibul Kabir, Masahiro Sasabe, and Tetsuya Takine applied imitation updating to aggregator selection, taking account of rational behavior of each node: Each node tries to select a strategy expected to lead to larger payoffs (i.e. residual battery) based on the strategies of neighboring nodes.

They first introduced a new game model taking into account the bundle retransmission when a sender cannot find an aggregator as its neighbor. Then, stable conditions were derived through theoretic analysis based on replicator dynamics on graphs. In addition, they discussed running condition where all nodes can survive without battery outage. To evaluate the validity of theoretic analysis and reveal feasible parameter settings achieving successful bundle transfer, simulation experiments were conducted using agent based dynamics. Both theoretic and simulation results presented appropriate parameter settings to achieve a system with desirable characteristics: Stability, survivability, and success probability in bundle transfer.

Even though imitation updating ordinarily works well, it has one drawback: Each node cannot change its strategy when all neighbors take the same strategy as that the node takes. Each node wants to avert such a situation because its main purpose is sending bundles to the sink node via the message ferry. To cope with this problem, also consider a system with *mutation updating* [52].

After reviewing all the above literature, we find that to select the strategy, Imitation Update rule of Evolutionary Game Theory has been used in [1] and [15]. Our aim in this work is to conduct a review on the latest bio-inspired techniques applied in game theory and develop the agent based dynamics of the Birth-Death update rule and analyze the simulation results.

1.3 Our Proposal: Developing a novel agent based dynamics for Birth-Death Update Rule

In this work, we are going to understand what Birth-Death update rule is. And then we are going to develop the novel agent based dynamics of BD update rule with the help of Netlogo software. For that, we are going to trail the following procedure:

i. Develop the modifier matrix for Birth-Death Update Rule
ii. Derive the replicator equation on graph for *Birth-Death* update rule
iii. Find the solution of BD update rule with the help of the replicator equation on graph and then find the suitable equilibrium conditions.
iv. Develop the agent based dynamics of the BD update rule.

v. Simulate the developed algorithm in Netlogo and analyze the outcome

1.4 Order of discussion

This thesis work is organized in the following order-

In chapter 2, short reviews on latest bio-inspired techniques in game theory will be discussed.

In chapter 3, a basic understanding of Delay Tolerant Network (DTN) will be provided.

In chapter 4, Evolutionary Game theory and Replicator Equation will be discussed.

In chapter 5, mathematical model and agent based dynamics will be developed.

In chapter 6, simulation as well as simulation outcomes will be discussed.

In chapter 7, conclusion of the thesis is discussed where recommendation for future work is given.

Chapter 2

A Summary of The Latest Bio-inspired Techniques in Game Theory

As a part of our thesis work, we have conducted a survey at length on the latest bio-inspired mechanisms which have been applied in decentralized wireless network as well as in DTN. Followings are the short reviews on the topics surveyed categorized into several segments-

2.1. Energy efficiency

Zoran et al [16] have addressed effect of cooperation on the energy efficiency in decentralized wireless networks without any "cooperation burden". While adopting game-theoretic framework, this paper- (1) does not focus on enforcing cooperation, (2) confines strategies to physical letter avoiding introduction of virtual currencies, (3) does not assume presence of altruistic nodes in network. In spite of assuming cooperation to be beneficial ""by default", this model proposes a "TIT-FOR-TAT" strategy where a node changes from defector to cooperator when it experiences benefit (increase of fitness) as result of the cooperative behavior of other node(s), and vice versa when there is no such benefit. As it is observed that, the introduction of a cooperator in the vicinity of a node involved in wireless transmission triggers cooperative behavior in that part of the network, even though the network nodes act in a selfish manner i. e. care only about their individual fitness.

In this paper [17], Le Treust et al showed that in a decentralized multiple access channel (MAC), transmitters with corresponding conflict of interest can have a predictable outcome i.e a Pareto-efficient repeated game equilibrium. While previous works on energy-efficient PC considered constant channel and single update of transmit power within one time block, this paper considers power levels update by the transmitters several times within a block which is called decentralized fast power control (DFPC). This PC scheme only requiring individual CSI, models a finitely repeated game (RG) and a discounted RG which incurs that it is possible to incite selfish transmitters to operate at lower powers, which leads to an equilibrium point that Pareto-dominates the one-shot NE point and SE point.

Works of Mariem Mhiri et al in this paper [18] mainly focuses on improving the energy-efficiency (EE) of a multiple access channel (MAC) system through power control in a distributed manner considering the possible presence of a queue at the transmitter, in contrast to previous work. Assuming that Nash Equilibrium (NE) is not always energy-efficient, Nash Bargain (NB) is considered a possible Pareto-efficient solution, requiring global transmitter at each transmitter node. The simulated model proves that even with a huge number of users, the Finite Repeated Game (FRG) can always be played with minimum number of stages shorter than when using the Goodman model. Finally, the comparison of cross-later algorithm with the Goodman algorithm show that in real systems with random packet arrivals, Goodman algorithm is outperformed by the cross-layer power control algorithm.

2.2. Intrusion detection

Animesh Patcha et al [19] concentrates on providing a mathematical framework for intrusion detection system (IDS) in MANETs assuming a host based IDS. It uses the concepts of multi-stage dynamic non-cooperative game with incomplete information to model intrusion detection. In this model, a malicious node attacks only one node at a time and collusion between malicious nodes are ignored. The IDS either sets off an alarm on detection of intrusion or does nothing. Also the model sets the rate of false alarms as the basic performance criteria for the IDS. There exists a tradeoff between reduction of false alarm by decreasing the sensitivity of system with the increase in rate of undetected intrusion. Although, either of those in extremes are tried to be avoided as the system becomes ineffective. This model considers undetected intrusion to be much more severe than the cost associated with false alarm.

A new Intrusion detection system (IDS) comprising a novel cluster-leader election process and a hybrid IDS has been introduced in this work [20]. This election process uses the Vickery-Clarke-Groves mechanism to elect the cluster leader to provide detection service.

This game theory based IDS models the detection as a non-cooperative Bayesian game between two competing players i.e. the leader (defender) and the malicious node (attacker) through activation of two hybrid IDS modules- lightweight and heavyweight modules. This models has been successful in minimizing the power consumption for IDS operation in MANETs along with achieving higher detection rate and reduced false alarm. Subba et al found the detection rate of lightweight and heavyweight modules to be 91.78% and 81.33% respectively.

A self-adaptive intrusion detection system has been introduced in this paper [21] which uses programmable, lightweight mobile agents and combines both host based and networks based IDSs. This paper also features a new learning phase which basing on basic rules, detects intrusion and if any ambiguity arises, takes decision from learning module to arrive at a conclusion.

2.3. Signal processing

Krishnamurthy et al [22] used statistical signal processing algorithms for computing state estimates in multi-agent sensing system. In an event of interest, mode selection by the sensors in the most efficient way has been explained with Bayesian global game whereas, social learning helps in subsequent sensors' evolved decision making to optimize its local utility selfishly by exchanging information. This work lacks the discussion of data incest problem.

Walid Saad et al [23] focused on the potential of applying game theory for addressing emerging problems in the field of microgrid management, demand-side management and communications. This paper discusses in details the problems in smart grids which can be solved by game theory also categorizes the game-theoretic tools which can be adopted in designing smart grids.

Chen et al built a framework to find a solution to the distributed power splitting problem of Simultaneous wireless information and power transfer (SWIPT) in relay interference channels using game-theoretic approach [24]. In the game designed, each link aims to maximize the individual payoff by choosing dedicated relay's power splitting ration.

Results showed that proposed algorithm could converge to Nash Equilibrium and achieve a near-optimal network-wide performance.

2.4 Cognitive radio networking

Chen et al proposes a game-theoretical anti-jamming scheme (GTAS) scheme as defense to jamming attacks [25]. Unlike previous works, this one achieved very good throughput with lower computation complexity. Markov Decision Process was chosen for jamming-hopping process with a proposal of Policy Iteration Scheme. This work also proposes a Q-function based approach to reduce the computation complexity. Performance evaluation demonstrated that GTAS was successful in achieving higher payoff than existing approaches and lower jamming probability.

Jiang et al integrates the design spectrum sensing and access algorithms together in this work [26] which distinguishes from previous works. This paper discusses the outcome of the integration in two scenarios: synchronous scenario where primary network is slotted and non-slotted asynchronous scenario. By devising a learning algorithm for secondary users (SU) as well as solving the joint replicator dynamics equation, more than one Evolutionary Stable Strategy (ESS) was obtained.

This work [27] of Liu et al puts forward a novel Dynamic Spectrum Access (DSA) algorithm for CRNs based on game theory which sheds light on the game behavior among SUs during a specific leased spectrum and efficiency for mutual interference between Secondary Users (SU). This model lets the SUs to maximize spectrum utilization rate in a dynamic scenario while utilizing the licensed spectrum shared with PU. This work further concludes that Stackelberg model improves spectrum utilization by increasing aggregated amount of SUs' leased spectrum.

Issues like energy and power constraints in Cooperative Cognitive Radio Network (CCRN) have been focused onto in this work of Cao et al [28]. A game-theoretic framework has been proposed and implemented to address optimal communication strategy to obtain highest PU-utility in an energy-aware CCRN.

2.5 Crowdsourcing

Moshfeghi et al addresses the problem of CS quality without compromising on CS benefits like low monetary cost and high task completion by modeling a n-person Chicken game. This work [29] derives a Bayesian Equilibrium (BE) for the n-player continuous-time chicken game representing a crowdsource scheme for a definite task. Simulation scenario further investigates dynamics which are intrinsic to the framework focusing on the aspects in which particular variations in workers' behavior can affect the dynamics of a scheme taking workers in and allowing them to leave.

This work [30] of Moshfeghi et al surmises that Task Completion Time (TCT) can be used as a powerful discriminative factor in identifying risk-inclined and risk-neutral workers. Considering two opposing forces- one pushing towards quickness and other towards correctness the hypothesis was evaluated using 35 topics from TREC-8 collection by designing an n-player chicken game model. This game model was formulated using incentives as a bait for careless (risk-inclined) workers, who respond to these in a characteristic way.

2.6 Rate adaptation protocols

A number of protocols in wireless networks lead to interactions among users that are subjective in nature and affect overall performance. This paper [31] discusses in depth analysis of interplay between wireless network dynamics and video transmission dynamics in light of subjective perceptions of end users in their interactions. Each user is driven by three conflicting objectives: QoE, QoS and transmission cost. This work proposes a concrete game theoretical framework that allows the optimal use of traditional protocols by taking into account the subjective interactions that occur in practical scenarios.

2.7 Cooperative framework

In this paper [32], we use game theory to study interaction between a malicious node and a regular node in wireless network with unreliable channels. We model malicious node detection process as a Bayesian game with incomplete info and show that a mixed strategy perfect Bayesian NE is attainable while the equilibrium in the detection game ensures the identification of the malicious nodes, we argue that it might not be profitable to isolate the malicious nodes upon detection. As a matter of fact, malicious nodes and regular nodes can coexist as long as the destruction they bring is less than the contribution they make. To show how we can utilize the malicious nodes, a post detection game between the malicious and regular nodes is formalized. Solution to this game shows the existence of sub-game perfect NE and the conditions that achieve the equilibrium.

In wireless networks, cooperation is proposed [33] to improve the channel capacity. As nodes in the network are autonomous agents, making decisions for only their own interests, game theory supplies sufficient tools to analyze the network users' behavior and action. Here, there is a source, destination and relay node with relay helping to enhance the communication between the source and the destination nodes. The main issue here is to choose a node that will act as a relay node to enhance communication. To solve this, with the help of game theory, cooperation incentives are devised so that the nodes can act as relay nodes. Later, challenges of applying game theory in this aspect is also discussed.

In this paper [34] a game theoretic framework for studying the problem of minimizing the delay of instantly decodable network coding for cooperative data exchange in decentralized wireless network is introduced. Here, clients cooperate with each other to recover erased packets without central controller. Game theory improves distributed solution by overcoming the need of central controller. The session is modeled by self-interested players in non-cooperative potential game. Utility functions are designed such that increasing individual payoff results in a collective behavior achieving desirable system performance.

In this paper [35], we investigate cooperative environmental monitoring for Pan-Tilt-Zoom (PTZ) visual sensor networks based on game theoretic cooperative control. In particular, we focus on one of the key goals of the monitoring task, i.e. monitoring environmental changes from a normal state. For this purpose, this paper first presents a novel formulation of the optimal environmental monitoring problem reflecting the above objective and characteristics of vision sensors. Then, the optimization problem is reduced to a potential game with potential function equal to the formulated objective function through an existing utility design technique, where the designed utility is shown to be computable through local computation and communication. We finally present a payoff-based learning algorithm, which refines [18] so that the sensors eventually take the potential function maximizes with high probability and local action constraints are dealt with. Finally, we run experiments on a test-bed in order to demonstrate the effectiveness of the presented approach.

2.8 Non cooperative framework

In sensor networks, it is very difficult to use sufficient energy due to limitation of energy in the sensor nodes. So, during transmission, to maximize the energy output, game theory is used as a solution. Here [36], non-cooperative game is suggested to in order to optimize systems. As a part of this, interference between different nodes in studied and nash for fixed channel conditions is also considered and optimum transmission power level is obtained.

2.9 Wireless multimedia sensor

Wireless multimedia sensor networks are involved with rate-adaptive applications such as video, audio and image and so high bandwidth or throughput is demanded. To maximize system throughput, a channel access mechanism based on evolutionary game is proposed [37]. Under this, users are assumed to be bounded rationality, in order to coordinate user's behavior in distributed manner, a NEW REWARD function is deduced. On its basis, a dynamic channel access algorithm and corresponding dynamic equations are designed for the mechanism which converge to NE with faster speed. Theoretical analysis and simulation results show that the reward function proposed can realize the maximization of system throughput and higher normalized utilities of users under framework of evolutionary game, and corresponding dynamic equation is globally asymptotically stable, besides, when user deviates because of bounded rationality, dynamic equation is still able to guarantee faster convergence and smaller performance deviation.

2.10 Location smoothing

Location estimation of mobile target is an important research in wireless sensor networks. However, the phenomenon of non-line of sight affects the accuracy of location estimating algorithms greatly. In order to improve the accuracy of location estimation of mobile targets, a game theory based location method algorithm in WSN has been proposed [38]. In proposed method, first estimate the initial locations of mobile target with a support vector regression model, and then use game theory to smooth the already estimated locations. In the game model, game based filter and noise generation are two game rivals. The game filter aims to minimize the objective function of game model and noise generator aims to maximize the same objective function. The proposal is of a differential game theory based algorithm for solving optimal resolution.

2.11 Heterogeneous wireless networks

The paper [39] proposes a utility function and game theory based network selection scheme to maximize accommodated number of calls, minimize handoff occurrence frequency and fulfill QoS requirements in heterogeneous wireless network. When a new call or a handoff call arrives, UGT would calculate the utility value and preference value for each candidate network based on QoS satisfaction of call request and cooperative game computation.

2.12 OFDMA network

In this paper [40], we present a joint game-theoretic approach to perform inter-cell interference coordination in uplink multi-cell orthogonal frequency division multiple access networks. The coordinated user scheduling and power allocation are considered simultaneously. We prove the existence of the joint-strategy Nash equilibrium (NE) in which both the user scheduling and power allocation strategy reach NE. Then, we design a distributed joint strategy iterative algorithm to perform interference-aware resource allocation where only partial information exchange is involved. Simulation results demonstrate the effectiveness of the proposed algorithm.

2.13 Wireless multihop network

This paper [41] addresses the minimum transmission broadcast problem in wireless networks and presents efficient solutions, including an optimal broadcast scheme and distributed game-based algorithm. Distinct from related work in the literature which typically assumes wireless links are reliable, we address the issue of broadcasting over both reliable wireless links and unreliable wireless links. Our main contributions are as follows: We first formulate the minimum transmission broadcast problems over reliable links and over unreliable links as two mixed integer linear programming (MILP) problems, respectively. This way, optimal broadcast schemes can be easily obtained using any existing MILP solver, for small-scale networks. For large-scale networks, we propose a distributed game-based algorithm and prove that the game-based algorithm achieves Nash Equilibrium. Using simulation, we confirm that compared with existing algorithms in the literature and optimal solutions obtained by our MILP techniques, the proposed game-based algorithm performs very well in terms of delivery ratio, the number of transmissions, and convergence speed.

2.14 Directional sensor network

A directional sensor network, where a lot of sensors are intensively and randomly deployed, is able to enhance coverage performances, since working directions can be partitioned into different K covers which are activated in a round-robin fashion. In this paper [42], the problem of direction set K-Cover for minimum coverage breach in directional sensor networks is consider. First, the problem was formulated as a game called direction scheduling game (DSG), which was proved as a potential game. Thus, the existence of pure Nash equilibrium can be guaranteed, and the optimal coverage is a pure Nash equilibrium, since the potential function of DSGs is consistent with the coverage objective function of the underlying network. Second, we propose the synchronous and asynchronous game-theoretic based distributed scheduling algorithms, which we prove to converge to pure Nash equilibria. Third, we present the explicit bounds on the coverage performance of the proposed algorithms by theoretical analysis of the algorithms' coverage performance. Finally, we show experimental results and conclude that the Nash equilibria can provide a near-optimal and well-balanced solution.

2.15 Cooperative communication

Amplify and forward (AF) cooperative communication scheme is modeled using Stackelberg market framework, where a relay is willing to sell its resources; power and bandwidth, to multiple users to maximize its revenue [43]. The relay determines the prices for relaying users' information depending on its available resources and the users' demands. Subsequently each user maximizes its own utility function by determining the optimum power and bandwidth to buy from the relay. The utility function of the user is formulated as a joint concave function in the power and the bandwidth. The existence and the uniqueness of the Nash equilibrium are investigated using the concavity of the utility function, and the exact potential game associated with the proposed utility function. The Nash equilibrium solution can be obtained in a centralized manner, which requires full knowledge of all channel gains of all users, which may be difficult to obtain in practice. In this sense, a distributed algorithm can be applied to obtain the power and bandwidth allocations with minimum information exchange between the relay and the users. Similarly, the optimum prices for the power and the bandwidth can also be obtained in a distributed manner. The convergence of the algorithms is investigated using the Jacobian matrix at the Nash equilibrium. Numerical simulations are used to verify the validation of the proposed framework.

2.16 Resource allocation

In this work [44] the aim is to design simple, distributed self-configuring solutions for the problem of route selection and channel and power allocation in multihop autonomous wireless systems using a game theoretic perspective. Three games with different levels of complexity was compared: a potential flow game where players need complete network knowledge, a local flow game requiring full information of the flow and a low complexity cooperative link game which works with partial information of the flow. All these games have been designed to always assure the convergence to a stable point in order to be implemented as distributed algorithms. To evaluate their quality, the best achievable performance in the system using mathematical optimization was obtained. The system is modeled with the physical interference model and two different definitions of the network utility are considered: the number of active flows and the aggregated capacity in bps. Results show that the proposed games approach the centralized solution, and specially, that the simpler cooperative link game provides a performance close to that of the flow games.

Wireless access networks are often characterized by the interaction of different end users, communication technologies, and network operators. This paper [45] analyzes the dynamics among these "actors" by focusing on the processes of wireless network selection, where end users may choose among multiple available access networks to get connectivity, and resource allocation, where network operators may set their radio resources to provide connectivity. The interaction among end users is modeled as a non–cooperative congestion game where players (end users) selfishly select the access network that minimizes their perceived selection cost. A method based on mathematical programming is proposed to find Nash equilibria and characterize their optimality under three cost functions, which are representative of different technological scenarios. System level simulations are then used to evaluate the actual throughput and fairness of the equilibrium points. The interaction among end users and network operators is then assessed through a two–stage multi–leader/multi–follower game, where network operators (leaders) play in the first stage by properly setting the radio resources to maximize their users, and end users (followers) play in the second stage the aforementioned network selection game. The existence of exact and approximated sub-game perfect Nash equilibria of the two–stage game is thoroughly assessed and numerical results are provided on the "quality" of such equilibria.

Heterogeneous networks with multiple femtocells and macrocells are considered in this work[46]. Femto-base stations (femto-BS) are constrained to allocate transmitting powers such that the total interference at each macro-user terminal (macro-UT) is below a given threshold. A power allocation problem is formulated as a concave game with femto-BSs as players and multiple macro-UTs enforcing coupled constraints. Equilibrium selection is based on the concept of normalized Nash equilibrium (NNE) . When the interference at a femto-user terminal (femto-UT) from adjacent femto-BSs is negligible, for any strictly concave nondecreasing utility the NNE is unique and the NNE is the solution of a concave potential game. Authors also propose a distributed algorithm which converges to the unique NNE. When the interference is not negligible, an NNE may not be unique and the computation of NNE has exponential complexity. Authors introduce the concept of weakly normalized Nash equilibrium (WNNE) which keeps the most of NNEs' interesting properties but, in contrast to the latter, the WNNE can be determined with low complexity. We show the usefulness of the WNNE concept for the relevant case of Shannon capacity as femto-BS's utility.

In this paper [47], a decentralized and self-organizing mechanism for small cell networks (such as micro-, femto and picocells) is proposed. In particular, an application to the case in which small cell networks aim to mitigate the interference caused to the macrocell network, while maximizing their own spectral efficiencies, is presented. The proposed mechanism is based on new notions of reinforcement learning (RL) through which small cells jointly estimate their time average performance and optimize their probability distributions with which they judiciously choose their transmit configurations. Here, a minimum signal to interference plus noise ratio (SINR) is guaranteed at the macrocell user equipment (UE), while the small cells maximize their individual performances. The proposed RL procedure is fully distributed as every small cell base station requires only an observation of its instantaneous performance which can be obtained from its UE. Furthermore, it is shown that the proposed mechanism always converges to an epsilon Nash equilibrium when all small cells share the same interest. In addition, this mechanism is shown to possess better convergence properties and incur less overhead than existing techniques such as best response dynamics, fictitious play or classical RL. Finally, numerical results are given to validate the theoretical findings, highlighting the inherent tradeoffs facing small cells, namely exploration/exploitation, myopic/foresighted behavior and complete/incomplete information.

Chapter 3

Ferry Assisted Multi Cluster DTN

It is known that DTN is a unique technique that enables communication and data transfer in situations where traditional networks are obsolete, i.e., where, physical end-to-end connectivity is not present [4, 15]. By using DTN technique, we can practically establish connectivity within a closed remote boundary using wireless equipped devices, where devices connect each other using Ad-Hoc networking.

This chapter discusses the Ferry-Assisted Multi Cluster DTN in details.

3.1 An overview of Delay Tolerant Network

DTN is a message-based store-and-forward overlay network architecture. Unlike IP networks that are based on fixed-length packets, DTN operates on application-defined data units (ADUs) called Bundles. Each bundle contains arbitrary application content in its payload, along with addressing and an extensible set of other protocol blocks. Unlike most IP-based protocols in which metadata is stored in protocol headers, bundle metadata may appear either before or after the payload, hence the term "block" is used instead of header. These blocks contain the address and policy information used for routing, as well as information relating to reliability protocols and security management. The blocks are extensible, both for purposes within the infrastructure, as well as for applications to attach additional content.

DTN can leverage persistent storage resources within the network to buffer bundle data while it is in transit. This is unlike most typical routers which buffer data only in volatile memory while it is being processed. In the DTN environment, storage is used to wait for connectivity to be restored to some destination before transmitting a message, or to save the state of the system in case of a power outage. In part as a consequence of this buffering design, bundles have a real-time expiration lifetime parameter that is set when the bundle is generated and controls how long the bundle should remain in the network before it is either delivered or proactively deleted to reclaim resources.

In DTNs, the current TCP/IP model cannot work well due to lack of continuous end-to-end connectivity. A store-carry-forward message delivery scheme and custody transfer mechanism is used in DTNs to confirm reliable transfer of bundles with custody among nodes, by delegating the responsibility of custody-bundle transfer through intermediate nodes in a hop-by-hop manner. Note that a bundle is the protocol data unit in DTNs. The intermediate nodes keeping custody bundles are called custodians.

Each custodian must reserve a sufficient amount of storage and energy for receiving and holding the custody bundles until their successful delivery or delivery expiration. Due to shortage of storage capacity, custodians sometimes face storage congestion, where they have to refuse to receive any custody bundle from other nodes. In addition, each battery-powered node has to be awake while holding the bundles. Since each custodian also generates its own custody bundles, it is naturally selfish in behavior and rejects requests of custody transfer from other nodes to save its storage as well as its energy. Intuitively, this problem is aggravated in long-term isolated networks. In such a situation, some movable vehicles referred to as message ferries can solve the storage congestion problem by actively visiting the network and gather bundles from custodians. Note that message ferries are equipped with a storage enough to carry collected bundles to the destination, i.e., a base station referred to as a sink node, and it can also supply energy to the custodians if required. When there are multiple isolated networks referred to as clusters, message ferries have to periodically visit those clusters and collects bundles from custodians there. This network architecture is suitable for wide area sensing. Note that each node in a cluster can directly/indirectly communicate with other cluster members through multi-hop communication but cannot communicate with nodes in other clusters due to long distances among them. A message ferry helps the inter-cluster communication by acting as a mediator between each cluster and the outer world via the sink node which serves as a connector to the Internet or to other sink nodes.

3.2 Applications of DTN

Although DTNs were originally conceived for interplanetary use, they may have a far greater number of applications on Earth. Here is a short summary of the possible applications [37]:

- **Space Agencies:** International Space Station communication (currently operational for research), interplanetary communication, future space-debris monitoring.
- **Military and Intelligence:** Mobile ad-hoc networks (MANETs) for wireless communication and monitoring, cargo tracking, search and rescue communication, unmanned aerial vehicle (UAV) communication and control.
- **Commercial:** Cargo and vehicle tracking (by road, rail, sea, and air), in-store and in-warehouse asset tracking, data transactions (e.g., financial, reservations), agricultural crop monitoring, processing-plant monitoring, communication in underground mines.
- **Public Service and Safety:** Security and disaster communication, search and rescue communication, humanitarian relief monitoring, smart-city event-response, smart transportation networks, smart electric-power networks, global airport-traffic control, infrastructure-integrity monitoring, unmanned aerial vehicle (UAV) communication and control, remote learning [11].
- **Personal Use:** Personal monitoring and communication in wilderness and urban areas, fire-and-forget text messaging. Environmental Monitoring: Animal migration, soil properties and stability, atmospheric and oceanographic conditions, seismological events.
- **Engineering and Scientific Research:** Network subject-matter experts, academic research by faculty and students.

3.3 Store-and-Forward Message Switching

DTN overcomes the problems associated with intermittent connectivity, long or variable delay, asymmetric data rates, and high error rates by using *store-and-forward message switching*. This is a very old method, used by pony-express and postal systems since ancient times. Whole messages (entire blocks of application- program user data)—or pieces (fragments) of such messages—are moved (forwarded) from a storage place on one node

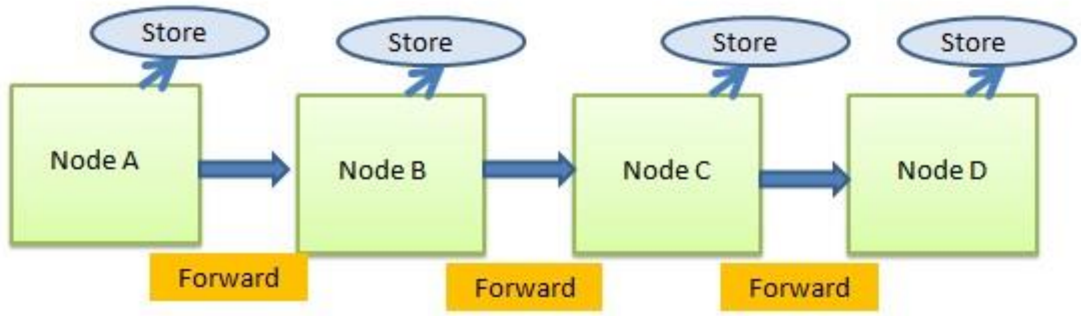


Figure 3.1 Store and Forward Technique

(switch intersection) to a storage place on another node, along a path that *eventually* reaches the destination. Store-and-forwarding methods are also used in today's voicemail and email systems, but these systems are not node-to-node relays (as shown above) but rather star relays; both the source and destination independently contact a central storage device at the center of the links.

The storage places (such as hard disk) can hold messages indefinitely. They are called *persistent storage*, as opposed to very short-term storage provided by memory chips and buffers. Internet routers use memory chips and buffers to store (queue) incoming packets for a few milliseconds while they are waiting for their next-hop routing-table lookup and an available outgoing router port. DTN routers need persistent storage for their queues for one or more of the following reasons:

1. A communication link to the next hop may not be available for a long time.
2. One node in a communicating pair may send or receive data much faster or more reliably than the other node.
3. A message, once transmitted, may need to be retransmitted if an error occurs at an upstream (toward the destination) node, or if an upstream node declines acceptance of a forwarded message.
4. By moving whole messages (or fragments thereof) in a single transfer, the message-switching technique provides network nodes with immediate knowledge of the size

of messages, and therefore the requirements for intermediate storage space and retransmission bandwidth.

In the DTN, the fundamental concept is an Architecture based on Internet – Independent Middleware, where the protocols at all layers are used that bets suite the operation within each environment, with a new overlay network called Bundle Protocol (BP) inserted between application & the locally optimized communication stacks. Military applications in the DTN areas are substantial, allowing the retrieval of critical information in mobile battlefield scenarios using only intermittently connected network communications. For these kinds of applications, the DTN protocol should transmit data segments across multi–hop networks that consists of different regional networks based on environmental network parameters. In all the cases, the operation requirements are differently altered and their performance is negatively altered rendering them Heterogeneous nature. The network uses variety of communication nodes, such as wireless, satellites, vehicle- mounted and unmanned aerial vehicle, to continuously advance message traffic even when there's an obstacle in the path that would stop traffic in the traditionally network. The delay tolerant networks makes the network to continue its function reliably in the environment where communications are most challenging and most critical and the message traffic continues to flow despite geographical or structural or malicious disruptions.

The DTN Architecture is designed to effectively operate as an overlay on top of regional networks or as an Inter Planetary internet. Moreover, the Delay Tolerant Network can overcome problems characterized by Long – Delays, Asymmetric Data Rates, Intermittent Connectivity, High Error Rates due to extreme environments, distances encountered in Space communication at Inter–Planetary scale competently when compared with the traditional Internet suite.

3.4 Custody Transfers

DTNs support node-to-node retransmission of lost or corrupt data at both the transport and the bundle protocols. However, because no single transport protocol (the primary means of reliable transfer) typically operates end-to-end across a DTN, end-to-end reliability can only be implemented at the bundle layer. The bundle protocol supports node-to-node

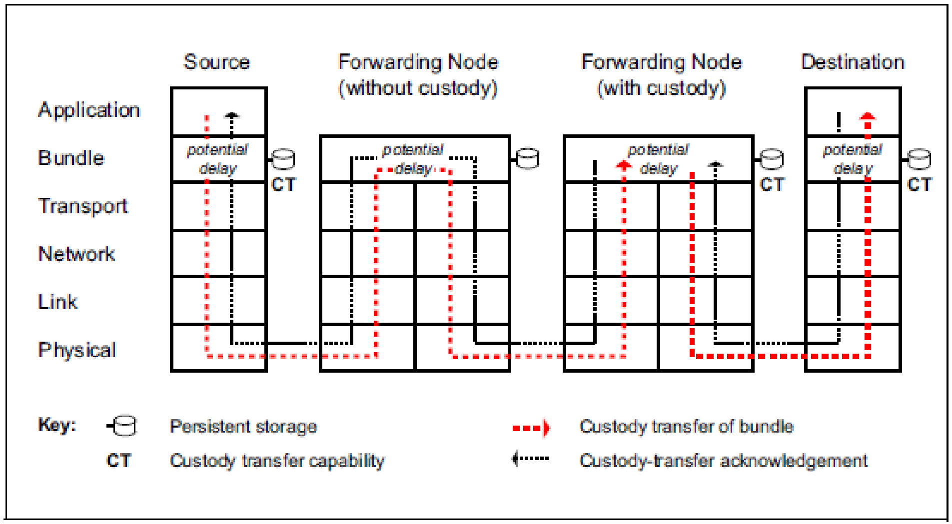


Figure 3.2 Custody Transfer Mechanism

retransmission by means of *custody transfers* [10]. Such transfers are arranged between the bundle-protocol agents' of successive nodes, at the initial request of the source application. When the current bundle custodian sends a bundle to the next custodian (not necessarily the next node in the path), it requests a custody transfer and starts a time-to-acknowledge retransmission timer. If the next bundle-protocol agent accepts custody, it returns an acknowledgment to the sender. If no acknowledgment is returned before the sender's time-to-acknowledge expires, the sender retransmits the bundle. The value assigned to the time-to-acknowledge retransmission timer can either be distributed to nodes with routing information or computed locally, based on past experience with a particular node. A bundle custodian must store a bundle until either (1) another node accepts custody, or (2) expiration of the bundle's time-to-live, which is intended to be much longer than a custodian's time-to-acknowledge. However, the time-to-acknowledge should be large enough to give the underlying transport protocols every opportunity to complete reliable transmission. Custody transfers enhance end-to-end reliability, but they do not guarantee it. Further enhancement can be achieved by using both the custody transfer and return receipt services.

3.5 Message Ferry

Message ferrying is a networking paradigm where a special node, called a message ferry, facilitates the connectivity in a mobile ad hoc network where the nodes are sparsely deployed. One of the key challenges under this paradigm is the design of ferry routes to achieve certain properties of end-to-end connectivity, such as, delay and message loss among the nodes in the ad hoc network. This is a difficult problem when the nodes in the network move arbitrarily. As we cannot be certain of the location of the nodes, we cannot design a route where the ferry can contact the nodes with certainty. Due to this difficulty, prior work has either considered ferry route design for ad hoc networks where the nodes are stationary, or where the nodes and the ferry move pro-actively in order to meet at certain locations. Such systems either require long-range radio or disrupt nodes' mobility patterns which can be dictated by non-communication tasks. We present a message ferry route design algorithm that we call the Optimized Way-points, or OPWP, that generates a ferry route which assures good performance without requiring any online collaboration between the nodes and the ferry. The OPWP ferry route comprises a set of way-points and waiting times at these way-points, that are chosen carefully based on the node mobility model. Each time that the ferry traverses this route, it contacts each mobile node with a certain minimum probability. The node-ferry contact probability in turn determines the frequency of node-ferry contacts and the properties of end-to-end delay. We show that OPWP consistently outperforms other naive ferry routing approaches.

3.5.1 Message Ferrying Model

In the Message Ferrying model, the devices in the network are classified into two categories [52].

(i) Regular nodes, or simply the nodes, that move according to some mobility model. These nodes generate data for other nodes in the network in the form of application layer data units called messages. At the same time, these nodes are interested in receiving the messages that other nodes have generated for them. For this work we assume that all the messages are unicast, i.e., they have a single unique destination. We assume that the movement of the nodes is driven by non-communication needs (e.g., a field-task assignment), and therefore this movement cannot be disrupted.

(ii) A single special node called message ferry (MF) that is responsible for delivering the messages between the nodes. The ferry achieves this by traversing a predetermined path repeatedly. We refer to each traversal through this route as a tour. We assume that both the ferry and the nodes are equipped with a similar radio of given small communication range. The nodes and ferry can communicate with each other only when they are within a distance of each other that is less than the communication range. The node and ferry are said to be in contact when they are within the communication range of each other.

We assume limited communication range because nodes may be energy constrained and may not be able to use long range communication channels that may require more power. Furthermore, while the ferry may be able to use a long range radio, the range of two-way communication between the node and the ferry would still be limited by the communication range of the nodes. Our model requires two-way communication for contact establishment. Similarly reliable data transfer between the nodes and the ferry, such as, using TCP, may also require two-way communication. During each successful contact, the ferry exchanges messages with the nodes. The ferry uploads the messages that the node has generated for other nodes, and downloads the messages that the ferry has for the particular node. The process is referred to as service. The ferry services only one node at a time. In the time between successive contacts, the nodes store the messages that they generate in a local buffer, called send buffer. We assume that the send buffer can hold a certain maximum number of messages, and once the send buffer is full, any new messages that the node generates are lost. We also assume that each node has a similar buffer for the messages that it receives; we call it the receive buffer. The receive buffer is used to store the messages that the node receives until they are consumed by the application layer at the node. We assume that the receive buffer for a node can hold a certain maximum number of messages. As the ferry takes the tour, it meets with different nodes. Upon meeting with a node, the ferry begins the download service, and continues until the ferry has downloaded all the messages that it has for the node, or, a timer, which we call the download timer, expires, or the receive buffer of the node becomes full, whichever occurs first. The ferry attempts to deliver any messages for the node that are left in its buffer at the end of download service in the next contact with the node. After the download service, the ferry starts the upload service. The ferry uploads the messages from the source buffer until all the messages in the source buffer of the node are uploaded, or a timer, called the upload timer, expires, whichever occurs first. Any messages that are left in the send buffer remain buffered until the next contact with the ferry. We refer to the messages that are left in the send buffer of the node as the residue messages. Please note that our model does not force strict order that the download service precede the upload service. These could happen simultaneously (if the radio channel permits), or in some multiplexed fashion. In general, performing download before upload reduces average delay, albeit slightly. Since both the ferry and the nodes are mobile in our model, we make a simplifying assumption that when the ferry and a node come in contact with each other, either the contact lasts long enough to complete the service, or they can pause, and exchange messages; usually the service time is short and does not amount to disruption in node mobility.

After the exchange the ferry continues with its route and the node continues with its movement. We assume that the ferry has infinite resources to move around and meet the other nodes, as well as to communicate with the other nodes when they come within its radio range, and to carry the messages between the nodes. Furthermore, we assume that we can route the message ferry in whatever way we want in the region where the nodes move. In this work the only constraints that we consider regarding the ferry are that the ferry cannot move faster than a certain maximum speed, and that it can only communicate with other nodes that are within a given radio range of the ferry.

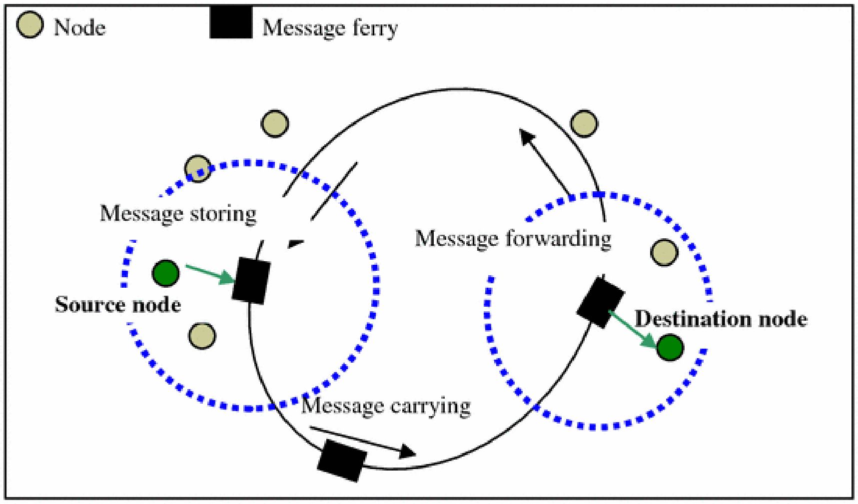
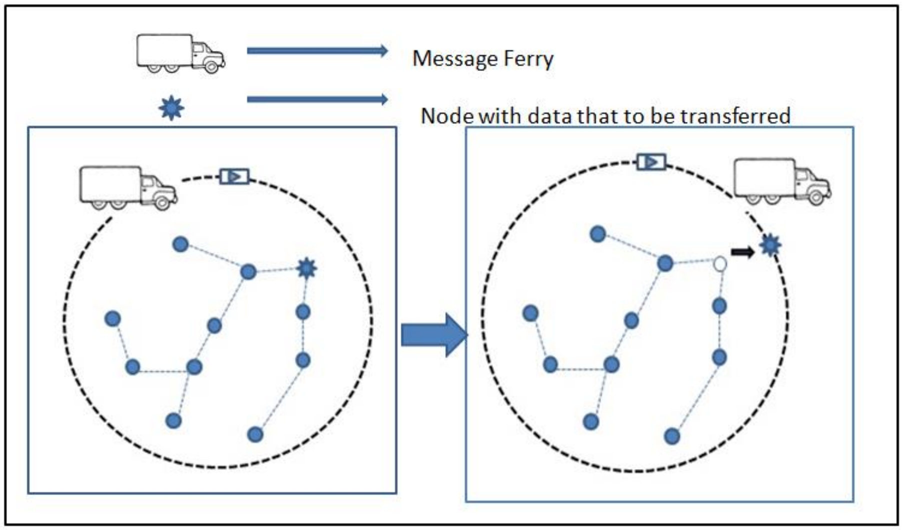


Figure 3.3 Message Ferrying Model

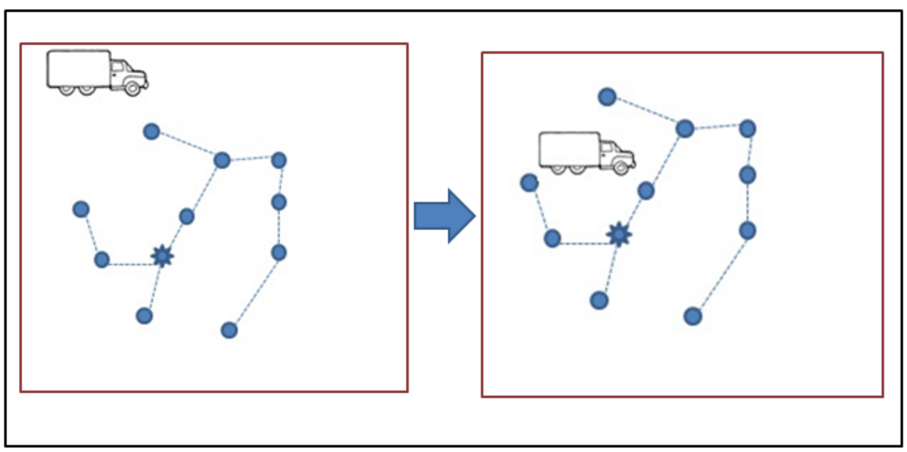
3.5.2 Message Ferrying Scheme types

There are two message ferry schemes [4]: Node-initiated message ferry scheme and ferry-initiated message ferry scheme. In the node-initiated message ferry scheme, ferries move around the deployed area according to known routes and communicate with other nodes they meet. In this scheme, node requires to be mobile. With knowledge of the ferry routes, node that wants to transmit the bundle periodically move close to a ferry route and communicate with the ferry (as shown in Figure 2.4(a)). In the ferry-initiated message ferry scheme, nodes are generally static and the message ferry move proactively to meet nodes. When a node wants to send bundles, it generates a service request and transmits it to the ferry using a long range radio. Upon reception of a service request, the ferry will adjust its trajectory to meet up with the node and collect bundles using short range radios (as shown in Figure 2.4(b)). In both schemes, nodes can communicate with distant nodes that are out of range by using ferries as relays.

In message ferry schemes, most communication involves short range radios. Long range radios are only used in ferry-initiated message ferry for small control messages, avoiding excessive energy consumption. By using ferries as relays, routing is efficient without the energy cost and the network load burden involved in other mobility assisted schemes that use flooding [4, 15].



(a) Node Initiated Message Ferry: Message Ferry travels in a fixed known route and nodes move close to message ferry routes to transfer data (Here nodes are mobile)



(a) Ferry Initiated Message Ferry: Message ferry visits each node that requests to transfer data (Here nodes are generally static)

Figure 3.4 Message ferrying scheme types

In ferry-assisted DTNs, regular nodes are assumed to have assigned tasks and limited in resources such as battery, memory and computation power. Ferries are special mobile nodes which take responsibility for carrying data between regular nodes and have fewer constraints in resources, e.g., equipped with renewable power, large memory and powerful processors. The purposes of ferries are to provide communication capacity between regular nodes. Message Ferrying is suitable for applications which can tolerate significant transfer delay, such as messaging, file transfer, email, data collection in sensor networks and other non-real-time applications. These applications would benefit from the eventual delivery of data even if the delay is moderate. For example, in a college campus, buses equipped with hard disks and wireless interfaces can act as ferries to provide messaging service to students; in battlefield and disaster relief environments, aerial or ground vehicles can be used as ferries to gather and carry data among disconnected areas. The design of the Message Ferry schemes is based on location awareness and mobility. Each node or ferry is aware of its own location, for example through receiving GPS signals or other localization mechanism.

After finishing this chapter we know that, DTN provides connectivity where internet can't provide any end to end connectivity. This chapter briefly describes about Delay Tolerant Network (DTN) with its history, Store and Carry forward switching, Custody Transfer, Application of DTN, Message ferrying scheme and model and Multi Cluster DTN.

In the next chapter, we will discuss about evolutionary game theory and replicator dynamics equation.

Chapter 4

Evolutionary Game Theory and Replicator Equation on Graph

In the last chapter, we elaborated on the basic structure of the ferry assisted multi-cluster DTN, message ferry schemes, and custody transfer and so on. In this chapter we discuss evolutionary game theory as well as replicator equation without which it is impossible to analyze and model the proper scenario of the DTN in this work.

4.1 Evolutionary Game Theory

Evolutionary game theory (EGT) is the application of game theory to evolving populations of life forms in biology. EGT is useful in this context by defining a framework of contests, strategies, and analytics into which Darwinian competition can be modeled. EGT originated in 1973 with John Maynard Smith and George R. Price's formalization of the way in which such contests can be analyzed as "strategies" and the mathematical criteria that can be used to predict the resulting prevalence of such competing strategies.

Evolutionary game theory differs from classical game theory by focusing more on the dynamics of strategy change as influenced not solely by the quality of the various competing strategies, but by the effect of the frequency with which those various competing strategies are found in the population.

Evolutionary game theory has proven itself to be invaluable in helping to explain many complex and challenging aspects of biology. It has been particularly helpful in establishing the basis of altruistic behaviors within the context of Darwinian process. Despite its origin and original purpose, evolutionary game theory has become of increasing interest to economists, sociologists, anthropologists, and philosophers.

The birth of evolutionary game theory is marked by the publication of a series of papers by mathematical biologist John Maynard Smith [49]. Maynard Smith adapted the methods of traditional game theory [7, 8], which were created to model the behavior of rational economic agents, to the context of biological natural selection. He proposed his notion of an evolutionarily stable strategy (ESS) as a way of explaining the existence of ritualized animal conflict. Maynard Smith's equilibrium concept was provided with an explicit dynamic foundation through a deferential equation model introduced by Taylor and Jonker. Schuster and Sigmund [38, 39], following Dawkins [9, 49, 50], dubbed this model the replicator dynamic, and recognized the close links between this game-theoretic dynamic and dynamics studied much earlier in population ecology and population genetics. By the 1980s, evolutionary game theory was a well-developed and firmly established modeling framework in biology.

Towards the end of this period, economists realized the value of the evolutionary approach to game theory in social science contexts, both as a method of providing foundations for the equilibrium concepts of traditional game theory, and as a tool for selecting among equilibrium in games that admit more than one. Especially in its early stages, work by economists in evolutionary game theory hewed closely to the interpretation set out by biologists, with the notion of ESS and the replicator dynamic understood as modeling natural selection in populations of agents genetically programmed to behave in specific ways. But it soon became clear that models of essentially the same form could be used to study the behavior of populations of active decision makers Indeed, the two approaches sometimes lead to identical models: the replicator dynamic itself can be understood not only as a model of natural selection, but also as one of imitation of successful opponents .

While the majority of work in evolutionary game theory has been undertaken by biologists and economists, closely related models have been applied to questions in a variety of fields, including transportation science computer science, and sociology . Some paradigms from evolutionary game theory are close relatives of certain models from physics, and so have attracted the attention of workers in this field. All told, evolutionary game theory provides a common ground for workers from a wide range of disciplines.

Evolutionary game theory (EGT) [7, 8] has grown into a field that combines the principles of game theory, evolution, and dynamical systems to interpret the interactions of biological agents. Practitioners in the field have used the theory to explain biological phenomena successfully, but EGT can also be used to interpret classical games from a different perspective. This document introduces evolutionary game theory and presents an evolutionary approach to the analysis of games. There are several basic components in the EGT analysis of games. Game agents and their strategies must be simulated with populations of players, the fitness of different strategies relative to the population must be computed, and a process to govern the evolution of the population must be defined. These simple components can be combined to yield highly complex solutions. Ideally, under the dynamical process the strategies of the populations of players will converge to some stable value. Evolutionary game theorists often claim the evolutionary solution of the game as the true definition of rational play.

Evolutionary game theory basically studies the behavior of large populations of agents who repeatedly engage in strategic interactions. Changes in behavior in these populations are driven either by natural selection via differences in birth and death rates, or by the application of myopic decision rules by individual agents.

When there are evolutionary conflicts between individuals (such as competition for resources) the best strategy to use may depend upon strategies used by other competitors. Game theory is used to make theoretical models of these situations which are usually subject to frequency dependent selection where the fitness of a morph varies with its frequency in the population.
Game theory is applicable only for two players. When this play will be played with infinite number of players, the game is going to evolve to a particular player .Then the game theory will be called Evolutionary Game Theory.

4.2 Replicator Equation

The natural selection process that determines how populations playing specific strategies evolve is known as the replicator dynamics. Slightly differing versions of these equations can be found in .There are different replicator dynamics depending on the evolutionary model being used.

The replicator equation [8, 9] is the first and most important game dynamics studied in connection with evolutionary game theory. It was originally developed for symmetric games with finitely many strategies.

Consider an evolutionary game with n strategies, labeled $i=1,\ldots..n$. The payoff matrix, A, is an $n \times n$ matrix, whose entries, $A = [a_{ij}]$, denote the payoff for strategy *i* versus strategy *j*. The relative abundance (frequency) of each strategy is given by x_i. We have

$$\sum_{i=1}^{n} x_i = 1 \qquad (4.1)$$

The fitness of strategy *i* is given by

$$f_i = \sum_{j=1}^{n} x_j a_{ij} \qquad (4.2)$$

For the average fitness of the population, we obtain

$$\Phi = \sum_{i=1}^{n} x_i f_i \qquad (4.3)$$

The replicator equation is given by

$$\dot{x}_i = x_i(f_i - \Phi), i = 1; \ldots n. \qquad (4.4)$$

This equation is one of the fundamental equations of evolutionary dynamics where dot represent the time derivatives. It describes evolutionary game dynamics (frequency dependent selection) in the deterministic limit of an infinitely large, well-mixed population.

Note that Equation (4.1) is applicable only to an infinitely large and well-mixed population where each player can equally play games with all other nodes.

4.3 Replicator Equation on graph

Replicator Equation on graphs is an extension of the original theory to a finite size population. Members of a population are represented by vertices of a graph and interact with connected individuals. It describes how the expected frequency of each strategy in a game changes over time within the graphs.

Let us introduce the $n \times n$ matrix also known as modifier matrix $M = [m_{ij}]$ (where m_{ij} describes the local competition between strategy *i* and *j*)

Note that Off-diagonal elements of matrix m is anti-symmetric, i.e. $m_{ij} = -m_{ji}$, that is ,

Table 4.1 Modifier Matrix

Node 2 / Node 1	Send	Aggregate
Send	**0,0**	***m*,-*m***
Aggregate	**-*m*, *m***	**0,0**

because the gain of one strategy in local competition is the loss of another. Further, diagonal elements m_{ii} and m_{jj} are always zero, suggesting that local competition between the same strategies results in zero.

By modifying the original pay-off matrix, a_{ij}, the Evolutionary game dynamics in a well-mixed population can be transformed into on a *k* regular graph. The modified pay off matrix,

$$A' = [a_{ij} + m_{ij}] \quad (4.5)$$

The expected payoff g_i for the local competition of strategy *i* is defined as

$$g_i = \sum_{j=1}^{n} x_j m_{ij} \quad (4.6)$$

Note that, the average pay-off of local competition of strategy of *i* sums to zero i.e.

$$\sum_{i=1}^{n} x_i g_i = 0 \quad (4.7)$$

We thus obtain the average payoff Φ of the population on graph to be

$$\Phi = \sum_{i=1}^{n} x_i(f_i + g_i) = \sum_{i=1}^{n} x_i f_i \quad (4.8)$$

which is same as previous equation.

Let,x_i denote the frequency of strategy*i*on *k* regular graph. The replicator equation on graph can be obtained as follows:

$$\dot{x_\iota} = x_i(f_i + g_i - \Phi), i = 1; \ldots n \quad (4.9)$$

where f_i, g_i, Φ is given in equation respectively.

Note that, as k increases, the relative contribution of g_i decreases compared to f_i and in the limit $k \rightarrow \infty$, the replicator equation on graph is reduce to regular replicator equation.

Chapter 5

Mathematical Modeling of Birth-Death update Rule

In the present chapter we will discuss about Self-Organized Data Aggregation Techniques, the intra-cluster communication, where, a fixed sink node collects bundles from nodes in isolated clusters with the help of the message ferry, as shown in Figure 3.1. Each node in a cluster can communicate with other cluster members within the transmission range, called neighbors, but cannot communicate directly with the sink node and/or nodes in other clusters due to the long distances among clusters. The message ferry serves the inter-cluster communication by visiting custodians in each cluster.

5.1 Self-Organized Data Aggregation Technique among Intra-Cluster Selfish Nodes

In intra-cluster communication, each node in a cluster can communicate with other cluster-members called "neighbor" within the transmission range but cannot communicate directly with sink node or nodes in other clusters due to larger distance in between them. That is why message ferry acts as the inter-cluster communicator by visiting aggregators or custodians in each cluster. Each node in DTNs is basically powered by a battery and it has to be always awake when holding the bundles. Since each custodian also generates its own bundles with custody, it may be selfish and reject requests for custody transfer from other nodes to save its storage as well as its energy. This means that the custody transfer mechanism fails without taking the selfishness of custodians into account.

So, there are two problems to be dealt with-

I. Within a given period of time, message ferry finds it difficult to communicate all storage-congested nodes in a given period of time.
II. Nodes act selfish by not storing others' bundles.

Taking above two challenges in consideration, we refer to an **Evolutionary game-theoretic approach** which takes into account the selfishness of the nodes.

In evolutionary game theory, we assume that fitness (payoff) of a species is determined by not only its own behavior (strategy), which is programmed by genes, but also the behavior of surrounding individuals: the more the fitness is acquired, the larger the population of the corresponding species is [51]. With the help of this scheme, we can finally select some special custodians referred to as aggregators, which are cooperative in nature and willingly hold bundles with custody of other nodes.

With that in mind, we developed a self-organized data aggregation technique called **Birth-Death Update Rule** by taking account of the challenges in a no-transmission scenario. With the help of the evolutionary game theoretic approach, our system can automatically select some aggregators, which are cooperative in custody transfer mechanism with other nodes referred to as senders. Therefore, the message ferry needs to collect the bundles only from the aggregators. Note here that in this scheme, each aggregator should keep awake to receive bundles from senders anytime and hold bundles until transferring them to the message ferry, while each sender wakes up only when generating and sending bundles, as well as deciding its next role. In addition, each aggregator can obtain energy supply from a message ferry only when it finds a sender among its neighboring nodes. In our scheme, each node appropriately selects its strategy (i.e. being a sender or aggregator) depending upon the strategy of the node with maximum payoff i.e. mother node in its neighbor. This interaction among nodes is modeled as a game in game theory.

We examine the characteristics of the proposed scheme by introducing a no-retransmission mechanism in the game model. In our proposed scenario, we only consider cases where sender does not need to transmit the data repeatedly to the aggregator and completes successful data transfer to the aggregator in the first attempt. Then we discuss the system stability through the analysis based on a replicator equation on graphs. From simulation experiments, we confirm the validity of the analytical results and evaluate the system performance in terms of successful bundle transfer, optimality of aggregator selection, and resilience to node failures.

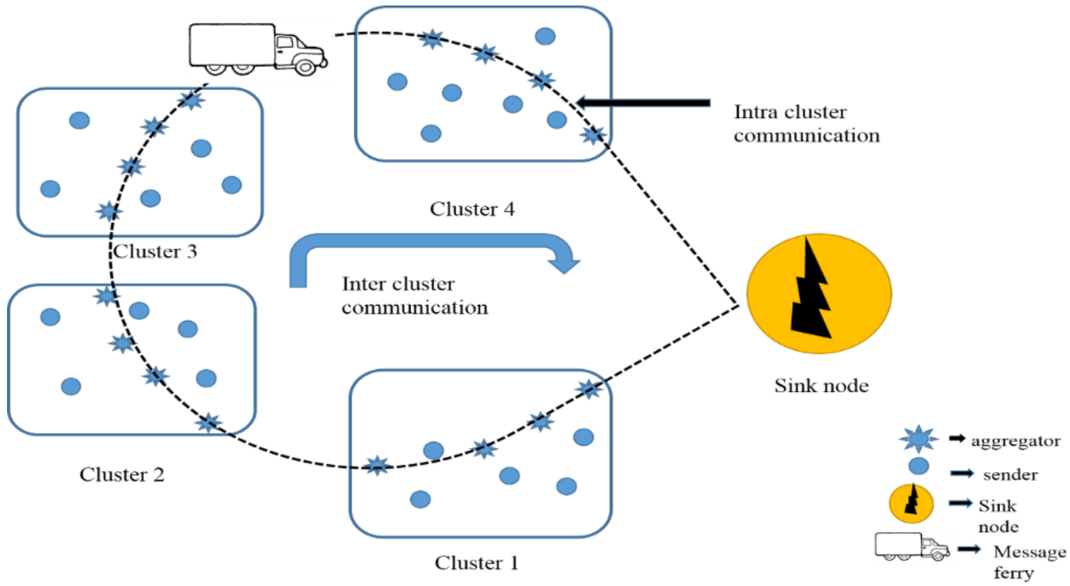


Figure 5.1 Model Scenario: Message ferry visits a limited number of aggregators in each cluster and delivers collected bundles to sink node (Inter Cluster)

5.2 Development of Pay-off Matrix

Now, the interaction among nodes can be modeled as a game between two neighboring nodes in evolutionary game theory [51], which is represented by a payoff matrix. In our scenario, there are two strategies for each node: to become an aggregator (aggregate) and a sender (send). There are four possible combinations of the strategies of the two nodes, and payoff of each node depends on the combination of strategies.

Table 5. 1 Payoff Matrix in no retransmission case

Node 2 / Node 1	Sender	Aggregator
Sender	***-s, -s***	***-s, b-c***
Aggregator	***b-c, -s***	***-c,-c***

Table 5. 2 Abstract payoff matrix

Node 1 \ Node 2	Sender	Aggregator
Sender	***R, R***	***S, T***
Aggregator	***T, S***	***P, P***

Let *c* and *s* denote the amount of energy consumption for aggregators and senders, respectively, per round. Obviously, $c \geq s$. *s* approaches *c* with the rate of generating bundles. The energy supplied by the message ferry to each aggregator is represented by *b*. intuitively, the larger *b* is, the more the aggregators increases. $b \geq c$ should also be satisfied to suppress the number of senders.

In summary, the benefit *b* is only a parameter for the sink node to control the number of aggregators in each cluster and should be carefully tuned by the sink node. We first model the bargain among nodes as a game between two neighboring nodes in evolutionary game theory. There are two roles (strategies) for each node: aggregator (aggregate) and sender (send). There are four possible combinations of the strategies of the two nodes as in Table 5.1.

We can abstract Table 5.1 into Table 5.2 where $T > S = R > P$ (no retransmission). In both cases, every node not only has a temptation to be an aggregator ($T > R$) but also a fear to be an aggregator ($S > P$). The larger *b* is, the more the temptation is. This indicates that the sink node can control the number of aggregators (senders) by changing *b*.

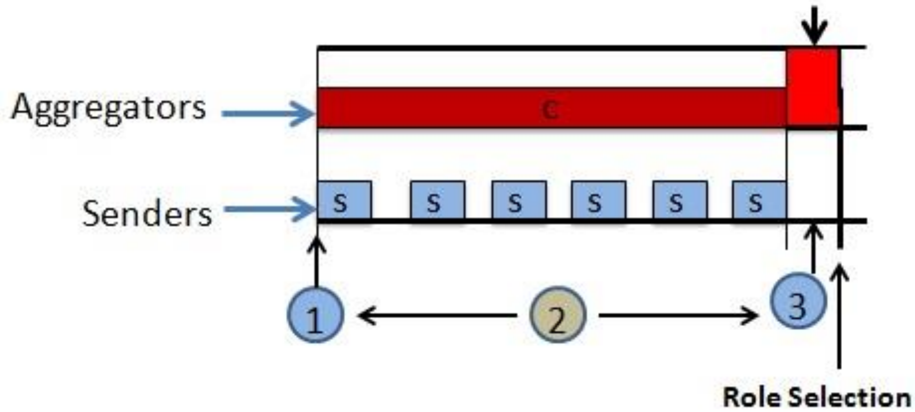


Figure 5.2 Energy consumption for no retransmission case

The resulting payoffs for each case can be modeled by taking the energy supply and energy consumption into account. If both nodes select to be aggregators, they lose the largest energy *c* without any energy supply from the message ferry, because they are not be able to collect a sufficient number of bundles to request the ferry to visit. An aggregator paired with a sender obtains the largest energy $b-c$; it loses c but obtains b from the message ferry. In this case, the corresponding sender loses the smallest energy s. In the case, when both nodes select to be senders and consume s (no retransmission). Here, they lose c in the worst case where the sender has to keep awake all the time in a round due to continuous retransmission.

The condition $T > R$ and $S > P$ also has another significant characteristic; taking a strategy different from the opponent is better than taking the same strategy as the opponent. As a result, both aggregating and sending strategies stably coexist [40]. Thus, with the help of the payoff-matrix and evolutionary game theory, when each node undertakes suitable strategies to optimize its own payoff, then the system converges to a fully stable situation where both senders and aggregators stably coexist.

5.3 Birth-Death Update Rule

A node (called mother node) is selected depending on its own payoff to update the strategy of randomly chosen neighboring node (called offspring node). The new updated strategy of the offspring node is changed similar to the mother node (which implies mother node is giving birth of its strategy).While updating, the previous strategy of offspring is deleted (which implies the strategy of offspring node is death). In Figure, node 1 is selected (here it is called mother node) to update the strategy of randomly chosen neighboring node 2 (here it is called off spring node) in (a).The new updated strategy of the offspring node is changed similar to the mother node (which implies mother node is giving birth of its strategy) in (b).While updating, the previous strategy of offspring is deleted (which implies the strategy of offspring node is death).

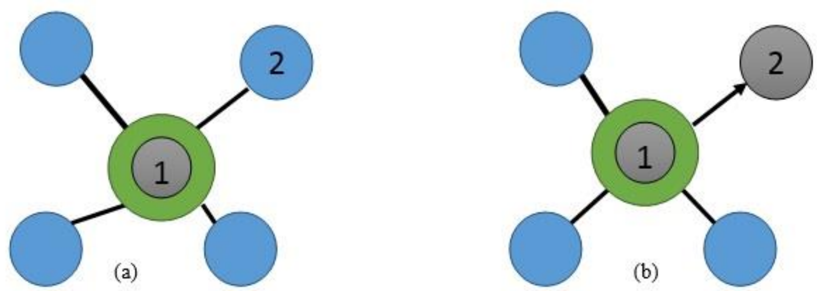


Figure 5.3 Strategy of Birth-Death Update Rule

5.4 Mathematical Model of the proposed scenario

Let x denote the ratio of the number of aggregators to the total number of cluster members. Note that $1 - x$ represents the ratio of the number of senders. For the no retransmission case, we use Table 5.1.

$x_1 = x$, denotes the ratio of Aggregators and $x_2 = 1 - x$, denotes the ratio of senders.

5.4.1 Birth Death- Update Rule (BD) for the case of no-retransmission

The Modifier Matrix for the case of BD is given by [46-48]

$$m_{ij(BD)} = \frac{a_{ii+}a_{ij-}a_{ji-}a_{jj}}{k-2} \tag{5.1}$$

The expected payoff (fitness) $f_{1(BD)}$ and $f_{2(BD)}$ of aggregators and senders can be obtained by substituting the value of Table 5.1 into Eq. (4.2) respectively.

$$f_{1(BD)} = x(-c) + (1-x)(b-c),$$
$$f_{2(BD)} = -s \tag{5.2}$$

The expected pay-off for local competition is obtained by putting the values of Table 5.1 (for the case of no retransmission) into Eq. (4.6) respectively.

$$g_{1(BD)} = (1-x)m,$$
$$g_{2(BD)} = -xm \tag{5.3}$$

The modifier matrix can be obtained by substituting the value of Table 5.1 into Eq. (5.1)

$$m_{ij(BD)} = \frac{b-2c+2s}{k-2} \tag{5.4}$$

The average pay off can be obtained by using Eq. (4.8) is

$$\Phi_{(BD)} = x_1\ [f_{1(BD)}\ + g_{1(BD)}\ ) + x_2\ (f_{2(BD)}\ + g_{2(BD)}\ ]$$
$$= (\ bx - s)(1-x) - cx \tag{5.5}$$

Finally the replicator equation on graph to become an aggregator is obtained by using Eq. (4.9)

$$\dot{x_1} = x_1[f_{1(BD)} + g_{1(BD)} - \Phi_{(BD)}]$$
$$= x(1-x)[\frac{-k(c-s) + bk(1-x) + b(2x-1)}{k-2}] \tag{5.6}$$

Substituting $\dot{x_1}$=0, there exists three equilibria $x = 0,1$ and

$$x_1{}^*_{(BD)} = \frac{b(k-1) - k(c-s)}{b(k-2)} \tag{5.7}$$

Note, equilibria is feasible if 0<x<1, i.e,

$$\frac{k}{k-1} < \frac{b}{c-s} < k \tag{5.8}$$

holds, where we use $c - s > 0$. We also have for all $k > 2$, $0 < \frac{k}{k-1} < k$. As a result, for any *c, s,* and *k*, there exists $b > 0$. Thus the equilibria is controllable and it can be shown to be stable.

Chapter 6

Development of Agent Based Dynamics for Birth-Death Update Rule and Simulation

Replicator dynamics is a powerful mathematical tool to predict the macro-level system behavior and it clarifies the effect of parameters on it. However, we can gain little insight into the micro-level system behavior such as the influence of irregularity or the topology on the system behavior, the geographical distribution of strategies, transient phenomena (including the convergence time to the equilibrium), and so on. Therefore we conduct simulation experiments based on agent based dynamics, which is a complementary method to understand the micro-level system behavior in the evolutionary game theory. It models such a phenomenon that a superior strategy spreads over the network in a hop-by-hop manner, where local interactions among neighboring nodes are defined explicitly. In agent based dynamics, each node interacts with neighboring nodes in every round and determines its strategy for the next round based on the acquired payoffs. In the case of Birth Death updating, a mother node is selected based on payoff, which then selects an offspring node and replicates its own strategy in the offspring node. Offspring selection is also done using payoff. In what follows, we conduct simulation experiments of agent based dynamics for two purposes: the validation of analytical results, and the investigation of the micro-level system behavior.

6.1 Agent-based Dynamics

In agent-based dynamics, each agent (i.e. node) interacts only with physically close nodes, called neighbors, rather than all other agents in the replicator dynamics. In DTNs, nodes within the transmission range of a node can be regarded as neighbors of the node. Any node and its neighbors together are called neighborhood of that node. Each node decides its behavior (a strategy) in the next round based on the information obtained in the preceding round. Agent-based dynamics reveals how the strategies, which are determined from local interactions, affect the performance of the whole system.

In every round, each node determines its strategy by comparing its own payoff with that of a randomly chosen neighboring node at the preceding round. Note that there is no assumption on the initial distribution of strategies. As we will see later, the initial strategy distribution almost does not have any influences on the system performance, except that it slightly affects the convergence time to the expected equilibrium. At the beginning of each round, mother nodes are selected based on maximum payoff within the neighborhood. Then each mother node u selects an offspring node v at random. Probability that the mother node will give its strategy to offspring node is H(u,v).

$$H(u,v) = \frac{Q_u - Q_v}{T - P}$$

Where, T-P (= b) represents the maximum payoff difference and Q_u and Q_v are average payoff of node u and v respectively. Since mother node has the maximum payoff within the neighborhood H(u,v) will always be positive. Thus, the more a strategy acquires the payoff, the more it spreads over the network through the Birth Death process in a hop by hop manner.

6.2 Simulation Model

Simulation experiments were conducted with NetLogo software, a multi-agent programmable modeling simulator. For simplicity, we assume that the duration of a round is fixed and each node periodically generates a fixed number of bundles per round. Therefore c and s are constant and set accordingly. In the following figures the average of 100 independent simulation experiment is plotted.

6.3 Simulation Results

We first study the transient behavior of the system. After that, we discuss the battery life of nodes and effect of topological structure.

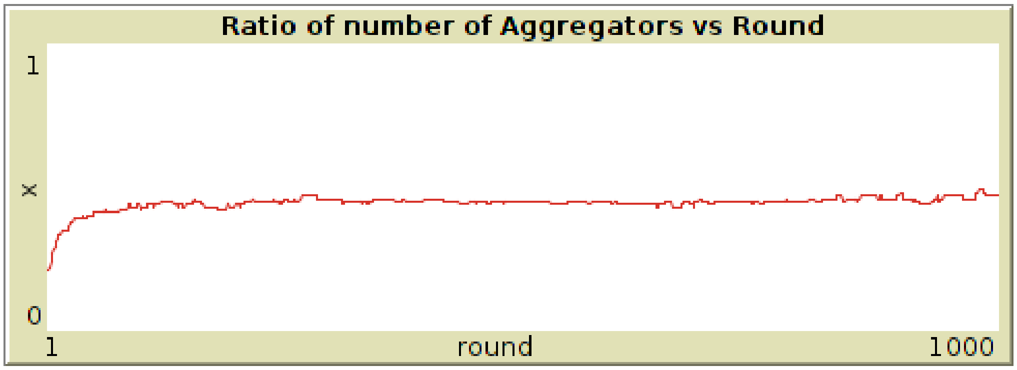


Figure 6.1 Equilibrium x_1* in k-regular graph (No-retransmission case b=14, c=10, s=.1)

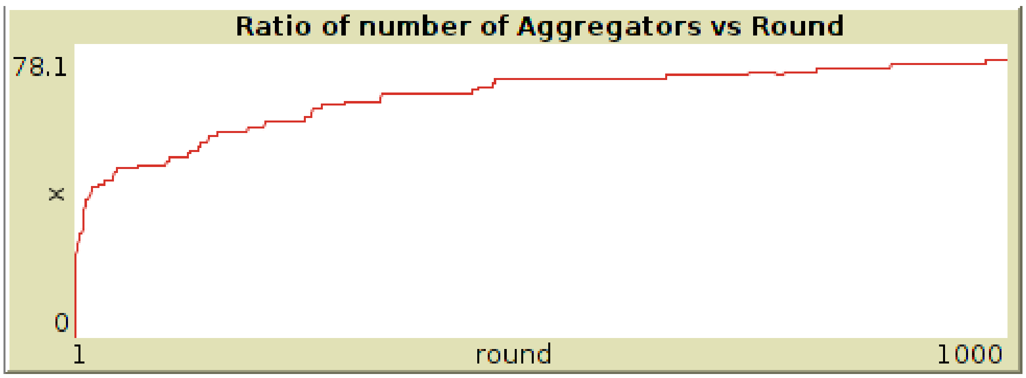


Figure 6.2 Number of alive node versus number of rounds. (b=14,c=10,s=.1)

6.3.1 Transient Behavior

We can observe in figure 1.1 how the ratio $x*1$ of aggregators converges to the equilibrium, where graphs are regular. And for all cases this equilibrium can be reached very quickly. This quick convergence property is suitable for achieving a stable system.

Next, we investigate the influence of the initial strategy distribution on the convergence property. Recall that the predicted equilibrium $x*1$ by the replicator dynamics is almost globally stable, i.e., if the initial value of x_1* is in (0, 1), the replicator equation converges to the equilibrium x_1*. Although the convergence time depends on the initial value of $x*1$, we found that $x*1$ converges to the same equilibrium almost at the same time.

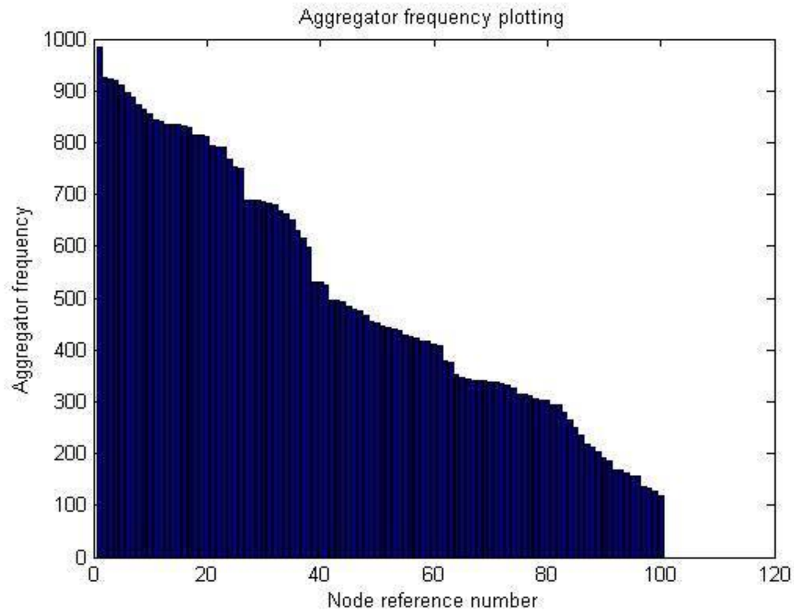


Figure 6.3 Probability of each node being an aggregator in a unit disk graph (No retransmission case, *k*avg = 14, *b* = 14 *c*/*s* = 100).

6.3.2 Battery life

Next, we examine the validity of the running condition. Note that every node initially has no

payoff. Each node obtains energy supply from the message ferry when it serves as an aggregator and has at least one neighboring node being a sender. Our aim is to achieve all nodes having positive cumulative payoffs, so that they can work permanently if they have a sufficient amount of initial battery. Figure 6.2 shows us that number of alive nodes are increasing as the time passes. Alive node means a node with cumulative payoff greater than or equal to one hundred. A base line for our better understanding that battery life of all nodes are increasing. So system will always be on running condition.

6.3.3 Effect on topological structure

So far we have shown the simulation results with *k*-regular graphs. We now consider unit disk graphs which are more realistic networks and are suitable for abstracting wireless networks. The unit disk graphs are generated by randomly located nodes in 2-dimentional space where two nodes are adjacent if the transmission ranges of the nodes mutually cover each other. By setting the number *N* of nodes to be 100 we set the area size to be 1 x 1 [km2], and the transmission range of each node is set to be 100 [m] in default. Note that we can control the average degree *k*avg by adjusting parameters

As we can observe that all nodes are not equally probable to become an aggregator. Some nodes become aggregator many times whereas some very few times. But we expect all nodes to have almost same probability of becoming an aggregator. To study this further, we observed the probability of a node becoming an aggregator with respect to degree of that node in figure 6.4.

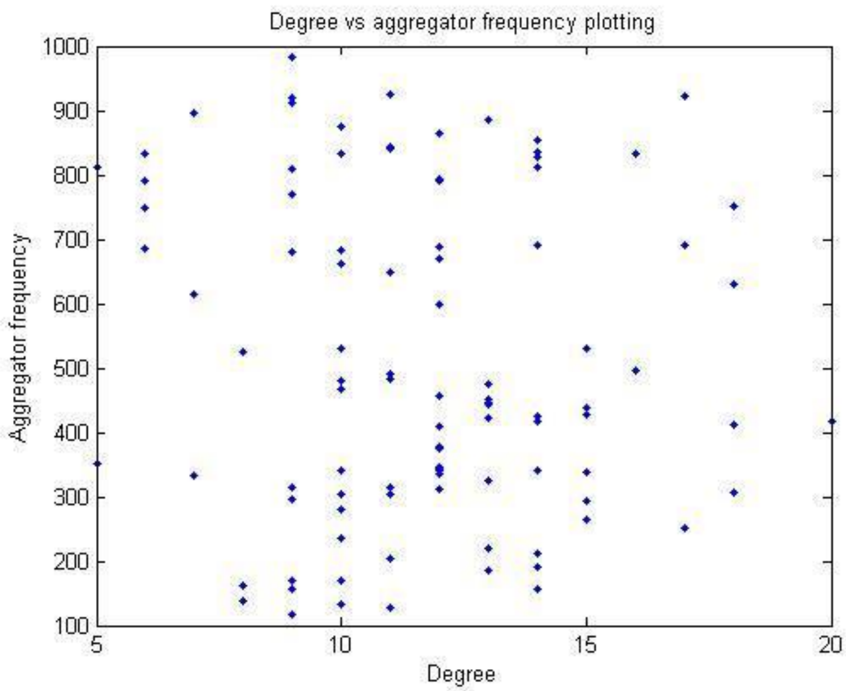


Figure 6.4 Degree vs. probability of each node being an aggregator in a unit disk graph (No-retransmission case, *k*avg = 12.96, *b* = 14, *c/s* = 100).

with higher degree has more tendency to become aggregators than nodes with less degree. Though some nodes with low degree also became aggregator in many rounds, but we can observe a upward shift of the points as we go from left to right in figure 1.4 (i.e. from lower degree to higher). We can now accept the unevenness of the probability with which a node has become an aggregator, as nodes with higher degree has more opportunity to collect bundles from other nodes.

This chapter considered data aggregation in a cluster for ferry-assisted multi-cluster DTNs. We considered that nodes were inherently selfish and non-cooperative in nature. Applying evolutionary game theory, we proposed the self-organized data aggregation scheme in such an environment. In this scheme, the selection of aggregators is conducted through decentralized processes with the help of strategic decisions of evolutionary game theory. The proposed scheme was evaluated and we found some characteristics very similar to the characteristics predicted by replicator dynamics. In particular, we can control the numbers of the aggregators by setting parameters adequately. Note that the controllable and stable equilibrium of the ratio of aggregators follows from the fact that a strategy different from the opponent yields a larger payoff. Therefore our proposed scheme also works well under such a situation that senders need to retransmit bundles when their transmissions fail and therefore they should be awake until their successful transmissions.

In addition, we discussed running condition where all nodes can survive without battery outage which is important for permanently living systems. Although all nodes didn't became alive but we plan to work on it.

We also discussed effect of topological structure on equilibrium. Here we observed that nodes in a random graph doesn't have similar probability of becoming an aggregator. Nodes with higher degree has the higher chance of becoming an aggregator.

Chapter 6

Conclusion

This thesis work was carried out with an aim to develop and simulate a novel agent based dynamics called Birth-Death Update Rule for the decentralized custody transfer in DTN. We considered that nodes were inherently selfish and non-cooperative in nature. Applying evolutionary game theory, the Self-Organized Data Aggregation scheme in such an environment is discussed. In this scheme, the selection of aggregators is conducted through decentralized processes with the help of strategic decisions of evolutionary game theory.

Chapter 2 included summery of latest bio-inspired techniques applied in game theory. Wide range of application-fields from signal processing to crowdsourcing etc are reviewed in this chapter.

Chapter 3 addressed about Ferry Assisted Delay Tolerant Network (DTN). It is known that DTN is a unique technique that enables communication and data transfer in situations where traditional networks are obsolete, i.e., where, physical end-to-end connectivity is not present. By using DTN technique, we can practically establish connectivity within a closed remote boundary using wireless equipped devices, where devices connect each other using Ad-Hoc networking.

Chapter 4 elaborated on Evolutionary Game Theory, Replicator Equation on Graph and Modifier Matrix. Self-Organized Data Aggregation techniques can be solved by the help of Evolutionary Game theory in order to take account of the inherent selfishness of the nodes for saving their own battery life which is described in this chapter. In Evolutionary Dynamics, Replicator Equation is one of the most fundamental equations. Note that, Replicator Equation is used for infinite number of players and Replicator Equation on graph is for finite number of players .That’s why, in our thesis, we use Replicator Equation on Graph.

Chapter 5 focused on development of the mathematical model for birth-death update rule. For this, abstract payoff matrix, pay off matrix for the case no retransmission case was discussed respectively.

In chapter 6, we developed the agent based dynamics of BD update rule also run the simulation in Netlogo software. We found out that-

I. with the agent based dynamics that we developed number of alive nodes increase with time
II. Game converges to the equilibrium very quickly
III. Nodes with higher degree have higher probability to be the aggregator

So, to summarize, in this work, we, at the very beginning conducted survey on latest bio-inspired techniques in game theory to look for the best suited mechanism for the data aggregation technique in ferry-assisted DTN. Next, we narrowed down our focus just onto a novel feature- the Birth-Death Update Rule and developed the replicator dynamics. Finally we simulated the developed algorithm of the proposed model in a no-retransmission scenario in Netlogo software.

This work can be extended further in future in comparing the simulation outcome with the outcomes of imitation update rule also in developing the replicator dynamics of the Death-Birth Update Rule and comparing the simulation outcome with that of the Imitation Update rule and Birth-Death update rule in Netlogo software.

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