Wireless Networks (2021) 27:1049–1062
https://doi.org/10.1007/s11276-020-02493-y

Analysis and modelling the effects of mobility, Churn rate, node's life span, intermittent bandwidth and stabilization cost of finger table in structured mobile P2P networks

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Accepted: 31 October 2020 / Published online: 19 November 2020

Abstract

Today P2P (Peer-to-Peer) networks are gaining popularity for sharing the contents. Due to massive spreading of Internet, these networks are also growing fast. MP2P (Mobile P2P) networks are attracting many users due to increase in the Internet-based mobile applications. These networks suffer from many challenges which are not considered for analysis and modelling adequately. We focus on few challenges like mobility of users, churn rate, intermittent bandwidth, shorter life span of mobile nodes, stabilization of finger table, etc. in this paper. We analytically analyse these challenges and define the effects of different parameters over the performance. Traditional P2P protocols are designed for wired networks and when these are implemented for mobile networks then mobility effect of users adds more challenge for researchers. We select two types of mobility models namely FF (Fluid Flow) and RWP (Random Waypoint) models to model the users' mobility. The churn rate of the mobile nodes makes network overlay management and content searching more difficult in MP2P networks. We select finger table-based protocols which are widely deployed in the P2P networks. But these protocols can't perform well in the mobile P2P networks due to mobility of the users. The mobility of the users and churn rate of the mobile nodes create failure in lookup of finger table and induce more cost to update the finger table. We consider these challenges and quantify the failure rate of mobile nodes, life span of mobile nodes, available bandwidth, cost of stabilization of finger table per node, etc. in this proposal. The proposed model is useful for modelling the performance of MP2P networks performance in various wireless environments like Mobile Ad hoc Networks (MANETs), Wireless Mesh Networks (WMNs), Wireless Sensor Networks (WSNs), Vehicular Ad hoc Networks (VANETs), Wireless LAN (WLAN), Wireless MAN (WMAN), etc.

Keywords Mobile P2P networks · Churn rate · Stabilization cost · Life span · Mobility rate

1 Introduction

P2P networks have attracted many users and research community due to recent developments in Internet based applications. P2P networks are distributed systems without any centralized controlling entity. These networks are IP based and mainly designed for wired networks, but these networks have gained popularity in wireless based networks also. There are many protocols developed and implemented for wired networks. But these protocols do not perform well for wireless networks due to many additional challenges of wireless communication. For example, mobility of the users, intermittent connection and limited bandwidth, churn rate, limited memory etc. We propose modelling and analysis of the effects of user's

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mobility, intermittent bandwidth, churn rate, expected life span of a node, stabilization cost etc. for structured mobile P2P systems in this paper.

P2P systems provide an open environment where nodes can participate autonomously and share their resources. There are two types of P2P networks-centralized and distributed. The distributed P2P networks are further classified into two categories- structured and unstructured. The structured P2P systems have a significant network structure (overlay) imposed over the participating nodes and it is tightly organised using DHT (Distributed Hash Table) [8] based protocols. IP addresses of nodes and files are mapped on same address space using Simple Hash Algorithm 1 (SHA-1). Most of the files discovering protocols in structured P2P networks like Chord [32], Pastry [26], Tapestry [40], etc. are based on the DHT [8].

The network topology of the participating nodes in structured MP2P networks is governed by ring topology. Examples of these schemes are Chord protocol [32] or Chord based protocols like MP-Chord [28], MR-Chord [35], AChord [9], Mobile Chord [21], Neighbour Selection in MP2P networks [36], Improved Structure for NN Chord [5], SelfChord [11], HPChord [13], VChord [12], BSRE (Binary Search Routing Equivalent) [22], etc. As per requirements of these protocols each node maintains a finger table which contains m $\geq$ 2 fingers. Fingers are successor and predecessor nodes in the MP2P networks. Each entry in the finger table contains a node identifier and its networks address (IP address and port number). The jth ($0 \leq j \leq m$) entry in the finger table for node i is defined as jth successor as given below.

$$\text{Successor (j)} = \left|i + 2^{j-1}\right| mod 2^m \text{for } 1 \leq j \ \leq m$$

According to the Chord or Chord based protocols, participating nodes form a ring overlay and each node in the ring is connected with one successor and one predecessor. The successors are referred in clockwise direction whereas predecessor is referred in anti-clockwise direction. As illustrated in Fig. 1, there are 15 active nodes in a MP2P network that form a ring overlay. For node N_{10}, successors are shown in Fig. 1. Nodes N_{13}, N_{17}, N_{20}, and N_{33} are successors of node N_{10}.

Chord or Chord based protocols are viewed as resource storing and retrieval protocol. Resources specially files and nodes are located in same address space which contains $0–2^m$ entries. The finger table is viewed as m identifiers intervals corresponding to the m entries in the table defined as $[(i + 2^{j-1}) \bmod 2^m, (i + 2^j) \bmod 2^m]$ for jth finger of node i. Each node is responsible for storing a small set of keys that fall between its predecessor and itself. So, each node is responsible for storing small portion of keys and this is how load is distributed among all the nodes in the

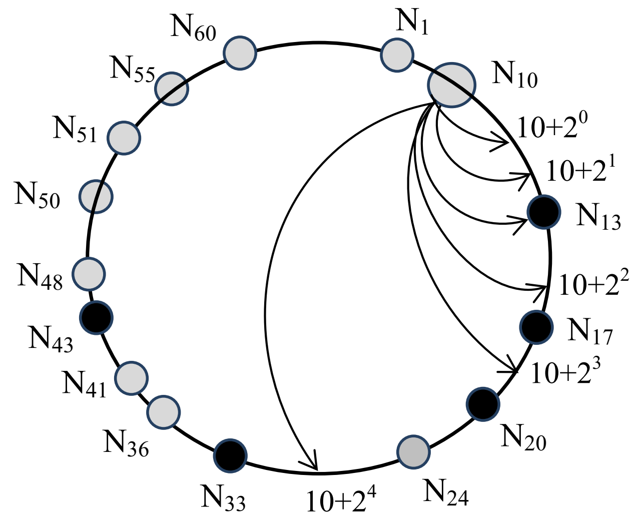

Fig. 1 Fingers of node N_{10}

MP2P networks. Search for a key k at node i is to find the immediate successor of node i or forwarding the search request to its largest finger in the finger table that precedes k. Each node can contain finger table up to O(log N) where N is the total number of nodes in the MP2P network. In mobile environment, nodes join and leave the network due to their wish or their mobility. So, finger table is periodically stabilized in order to keep it updated. When a node joins or leaves the system, finger table requires update which is $O(\log^2 N)$. After each joining or leaving of a node, additional cost of transferring keys O(1/N) is imposed. The major resources to be shared are files, CPU cycles, storage and bandwidth. Today, the main applications of P2P networks are files sharing, live video streaming, watching live TV, etc.

MANETs, WMNs, WSNs, VANETs have huge potential in many areas like disaster management, defence communications, fast infrastructure replacement, extension of the hotspots etc. MANETs and WMNs can easily replace the infrastructure-based communications without any pre-existing infrastructure or with very little infrastructure. In a MANET, autonomous mobile nodes communicate with each other in P2P communication mode which is without support of pre-exiting infrastructure. WMNs are formed over mesh backbone which comprises quasi-stationary or stationary wireless mesh routers to communicate with mobile nodes. Apart from these networks, WLAN and WMAN are also deployed for mobile communication with very little pre-exiting infrastructure and can support MP2P communication.

In all above networks, nodes can form structured MP2P network and communicate with other nodes in P2P communication mode and such communication is without support of the any pre-existing infrastructure. There are many challenges in these networks for P2P communication and there is still scope of work to be done for modelling and analysis of the challenges. In this paper, we propose analytical modelling and analysis of the effects of challenges like user's mobility, intermittent bandwidth, churn rate, expected life span of a node, stabilization cost etc. for structured MP2P systems. We present detailed discussion about the performance of various parameters in different circumstances. Rest of the paper is organized as follows. The literature survey and mobility modelling are given in Sect. 2. The proposed system modelling and performance analysis haves been discussed in Sect. 3. The conclusion about the performance of the proposed model is given in Sect. 4 followed by references.

2 Related works

MP2P network is an example of intermittent-connectivity networks. An intermittent-connectivity network is a wireless network in which participating nodes may have mobility and this is why nodes interact with others intermittently. Further, delay-tolerant network is an intermittent-connectivity network and such networks are gaining popularity in the networking community now days. DTNRG (Delay Tolerant Networking Research Group) primarily focuses on data delivery in frequently partitioned networks with anticipated movement of nodes [29]. In mobile networks, the location anticipation of node is important for delivery of the services. There are many schemes proposed for anticipating or deciding the location of mobile nodes. INS (Inertial Navigation System) is also useful in deciding the location and speed of the mobile equipment [4, 25]. Different schemes for providing location-based services in P2P overlay have been proposed in [2, 16, 24].

Sok-Ian Sou and Hsiu-Fang Ho have proposed analytical modelling of session completion in sparse vehicular networks [31]. In this proposal, authors have considered the path of vehicles covered by APs (Access Points) and each AP has its own communication range. Authors have proposed the probability of session completion within the coverage area of an AP. It is reported in [1, 30] that human movement has complex temporal and spatial correlations and its characteristics are not fully understood. So, it is unfair to say that human mobility modelling has been done completely as per realistic scenario. Our motivation of this paper is not to solve the open challenge, but to provide good quantification of the different parameters and their effects over performance in structured MP2P networks.

Chung-Ming Huang, Tz-Heng Hsu, and Ming-Fa Hsu have proposed a network-aware P2P file discovery scheme for the wireless mobile network [14]. The entire network is divided into different clusters. Nodes in a cluster share similar characteristics and a super node is proposed to maintain the indices of the files. MR-Chord (Mobile Robust Chord) scheme [35] has been proposed by Isaac Woungang, Fan-Hsun Tseng, Yi-Hsuan Lin, Li-Der Chou, Han-Chieh Chao and Mohammad S. Obaidat. In this proposal additional information about lookup success/failure rate are stored in the finger table along with chords and accordingly stabilization is performed. A topology-aware Chord protocol has been proposed in [9] for structured MP2P networks and there are two tables namely finger table and neighborship table proposed in order to improve routing efficiency and lookup accuracy.C. L. Liu, C. Y. Wang and H. Y. have proposed a cross-layer Chord-based design scheme called Mobile Chord, which enhances the P2P lookup performance over VANETs [21].

In [6], Shiping Chen, Yan Qiao, Shigang Chen and Jianfeng Li have proposed a scheme to find out the cardinality of the mobile nodes in large MP2P networks. In this proposal authors have proposed two methods namely circled random walk and tokened random walk to find out the number of nodes in the large MP2P systems. In [34], Shengling Wang, Min Liu, Xiuzhen Cheng, Zhongcheng Li, Jianhui Huang and Biao Chen have proposed a scheme to deal with intermittently connected nodes in MP2P networks. There are two proposed algorithms which exploit the spatial locality, spatial regularity, and activity heterogeneity of human mobility to select the relays. In [27], Haiying Shen, Ze Li and Lei YuTo have proposed a routing mechanism for hybrid wireless networks based on P2P based Market-guided Distributed Routing (MDR) mechanism.

In [36], XIA Hailun, WANG Ning, and ZENG Zhimin have proposed an ECPS (Effective Capacity Peer Selection) scheme for mobile P2P networks based on effective capacity of the participating nodes in MP2P networks. In this scheme, the selection of neighbour node has been modelled using the MADM (Multiple Attribute Decision Making) theory. MADM theory considers multiple parameters of participating nodes like SINR (Signal to Interference and Noise Ratio), residence time, power, security, speed, and bandwidth capacity. In [32], authors have proposed a Bidirectional Neighbor's Neighbor Chord routing scheme that can be used to improve the lookup performance in Chord-based P2P networks. In this scheme, the lookup is processed through clockwise and anticlockwise to improve the lookup performance.

Today, networks like MANETs, WMNs, VANETs, WLANs, WMANs etc. are gaining popularity due to less infrastructure requirement and these networks can be deploy in urban as well as rural areas very easily. MP2P communication is also acquisitioning popularity due to spreading of these networks. In our proposal, we consider the mobility pattern of the users in the urban cities. It has been observed and reported in [23] that users follow regular and fixed mobility pattern in the urban cities as shown in Fig. 2. Users follow highways, metros, buses and other transportation modes to do their daily activities. When users are in their offices or homes then their mobility is restricted to limited area and switch their movement direction frequently i.e. users have zig-zag type of mobility. Such mobility can be modelled by RWP (Random Waypoint) mobility model. When users follow highway or longer movement then their mobility can be modelled by FF (fluid flow) mobility model.

Referring to Fig. 2, an user starts his journey from his home and follows different paths and may use different modes of transportation to reach his office. The user stays in his office during office hour and follows limited movement which is restricted to nearby office. User returns to his home and stays at his home. Apart from office and home, user may go to malls, cinema halls, shopping complexes, etc. for his daily needs. We divide the user's movement in two category- movement on the longer path and restricted movement and accordingly we selected two mobility models namely fluid flow and RWP models to model the movement. We have assumed that the user communicates with other users in wireless mode in limited communication range with radius R (m). The communication establishment follows well-established procedure and protocols. As illustrated in Fig. 2, the mobility pattern of the mobile users in urban cities can be modelled and analysed using mobility models namely FF (Fluid Flow) and RWP (Random Waypoint). In this paper, we propose analytical modelling and analysis of the effects of user's mobility pattern and its effect over expected life span of a node along with other challenges in MP2P networks.

3 Proposed analytical modelling and analysis

In our proposal, we model the different parameters which are applicable in structured MP2P networks. We assume that each node in MP2P network implements Chord [32] protocol or Chord [32] based protocols [5, 9, 11–13, 21, 22, 28, 35, 36] to maintain the overlay. Each node maintains a finger table with m chords (fingers) and it is updated on regular basis to keep information updated in view of mobility and churn of nodes. We used the following parameters in our analytical modelling and performance analysis. The numeric values of different parameters are considered as taken in existing works.

We define the SMR (Session to Mobility Ratio), ρ_s(-probability of a session arrival) and ρ_m(probability of crossing MP2P communication boundary) similar to the notion discussed in [7, 10, 18, 19, 33, 37, 38]. We assumed that a node crosses the boundary of MP2P communication i number of times between two consecutive MP2P sessions. We define SMR = λ_{sr}/λ_m and ρ_s and ρ_m as follows.

$$\rho_s = \frac{\lambda_{sr}}{\lambda_{sr} + \lambda_m} = \frac{SMR}{1 + SMR} \tag{1}$$

$$\rho_m = \frac{\lambda_{sr}}{\lambda_{sr} + \lambda_m}\left(\frac{\lambda_m}{\lambda_{sr} + \lambda_m}\right)^i = \rho_s\left(\frac{1}{1 + SMR}\right)^i \tag{2}$$

3.1 Residence time and mobility models

We have selected two mobility models namely FF (Fluid Flow) and RWP in our proposal. FF mobility model is useful for node's mobility on the highway side. FF mobility model has been proposed in [23] to compute the boundary crossing rate of mobile nodes who gather in close proximity. It is assumed that communication range of mobile nodes is circular with radius R (m) and different communication ranges exist in closed region. To apply FF mobility model as proposed in [23], there are two

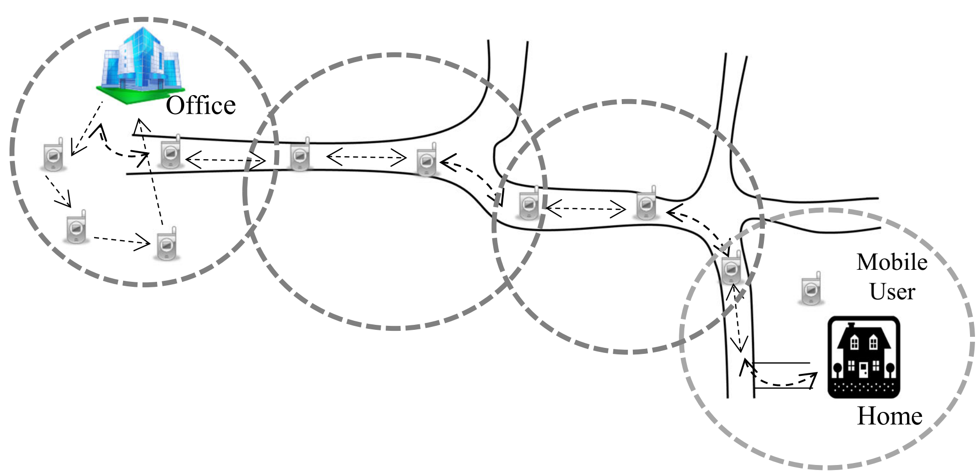

Fig. 2 Mobility pattern of mobile user

assumptions made. Firstly, the mobile nodes are uniformly distributed over the region and secondly the movement of each mobile node is uniformly distributed over [0, 2π]. The velocity of each mobile node is independent and identically distributed over the regions. We suppose λ_m and V are rate of crossing communication range per unit time and velocity (m/sec) respectively. The residence time of a mobile node in a communication area is the mean value of mobility rate as $1/\lambda_m$. According to FF mobility model, mobility rate (λ_m) of a mobile node is defined as follows.

$$\lambda_m = \frac{P_{CR} \times V}{\pi \times A_{CR}} = \frac{2V}{\pi R} \quad (3)$$

where P_{CR} and A_{CR} are perimeter and area of the communication range respectively.

Mobile nodes have restricted mobility in closed area and it may be in zig-zag type as shown in Fig. 3. For such movement RWP mobility model is useful. In urban cities when mobile users do their jobs or marketing or other things in closed region then they used to follow zig-zag type of the movement. RWP mobility model has been proposed in [3, 15, 20, 28]. In [20, 28], authors have proposed improved RWP mobility model in which random direction of mobile node is uniformly distributed over [0, 2π] and waypoints are chosen as Markov process rather than independent identically distribution. A mobile node starts travelling at some point and moves in straight line up to next point and then changes its movement direction. The travel length in straight line between two points is called transition length. If transition length is short then mobile node moves in zig-zag motion. Mobile node may travel in straight line like the movement on the highway and residence time in a cell is inversely proportional to the speed. The mean residence time of a mobile node in a communication area without pause time at exit of the communication range is given as follows.

$$R_{res(rwp)} \approx \chi \times \frac{P_{CR}}{4V} = \frac{\chi \pi R}{2V} \quad (4)$$

where $\chi \in \left\{\frac{\sqrt{3}}{2}, 1\right\}$ is a constant.

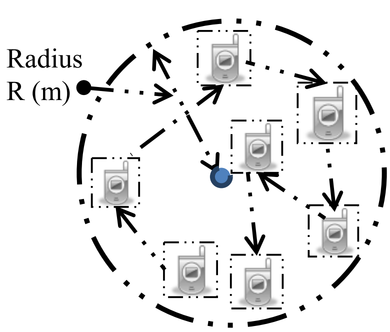

Fig. 3 Communication area and zig-zag motion in mobile P2P network

Sometimes, mobile node moves in more zig-zag motion as shown in Fig. 3 and residence time is different than what is defined in (4). We suppose that γ is the mobility factor such that $0 \le \gamma \le 1$ and V is uniformly distributed over $[V_{max}, V_{min}]$ then mean residence time of a mobile node in a communication range is given below.

$$R^{mean}_{res(rwp)} = \frac{\log V_{\max} - \log V_{\min}}{2\sqrt{\gamma}(V_{\max} - V_{\min})} \times P_{CR} \quad (5)$$

The transition length between two successive waypoints is defined as Eucludian distance and described as a stochastic process $\{L_n\}n\in N$where L_n are independent and identically Rayleigh distributed with mean value

$$E(L_{tr}) = \frac{1}{2\sqrt{\gamma}} \quad (6)$$

We suppose that a mobile node moves $i \ge 1$ number of times and remains in the same communication range. If node's velocity remains constant then mean residence time is defined as follows.

$$R^{mean}_{res(rwp)} = \sum_{i=1}^{\infty}(1-\rho_m)^i \frac{P_{CR}}{2\sqrt{\gamma}V} = \frac{R}{\sqrt{\gamma}V\rho_m} \quad (7)$$

If velocity of the mobile node is not constant then we take average speed as defined in [39] as given below.

$$V_{avg} = \frac{Average\ Transition\ Length}{Average\ Transition\ Time} = \frac{V_{max} - V_{min}}{\ln\left(V_{max}/V_{min}\right)} \quad (8)$$

We suppose that a mobile node moves $i \ge 1$ number of times and remains in the same communication range and speed of node varies between V_{max} and V_{min} then mean residence time is defined below.

$$R^{mean}_{res(rwp)} = \sum_{i=1}^{\infty}(1-\rho_m)^i \frac{P_{CR}}{2\sqrt{\gamma}\frac{V_{max}-V_{min}}{\ln\left(V_{max}/V_{min}\right)}} = \frac{\pi R}{\sqrt{\gamma}\rho_m \frac{V_{max}-V_{min}}{\ln\left(V_{max}/V_{min}\right)}} \quad (9)$$

The value of mobility factor (γ) decides the movement pattern of the mobile nodes. If value of γ is higher, it reflects more zig-zag motion with shorter transition length otherwise less zig-zag motion with longer transition length. The shorter transition length implies that mobile node changes its direction frequently. For example, it happens when a mobile user goes for shopping in a mall and changes his movement direction frequently. The larger value of transition length implies less change in the movement direction of mobile user. It happens when mobile user travels in a straight direction. So, value of mobility factor (γ) decides different kind of mobility of the mobile users.

The residence time of a mobile node in the area of communication range R = 100 m has been illustrated in Fig. 4. The value of mobility factor γ = 0.4 and probability ρ_m = 0.5, 0.7, 0.9. The speed of mobile node varies from 1 to 10 m/sec. The lower value of mobility factor shows less zig-zag motion with longer transition. The increase in the ρ_m shows the higher probability of mobile node to cross the communication boundary. It is obvious from this illustration that residence time of mobile node is inversely proportional to the speed of the mobile node in both the mobility models namely FF and RWP. But residence time in RWP model is much more than FF model. This is due to the zig-zag motion of the mobile node in RWP model. The residence time of mobile node is inversely proportional to the speed of the mobile node as well as probability ρ_m.

Referring to Fig. 5, we have selected the speed of mobile node V_{avg} = 5 and 10 m/sec, communication range R = 100 m and ρ_m = 0.5. The mobility factor (γ) varies from 0.1 to 1. We observed, when γ = 0.1, the residence time of the mobile node is maximum in RWP mobility model and it is constant in FF mobility model for constant parameters V and R. It is obvious that as γ increases then residence time decreases. This is due to the effect of the mobility factor (γ) over the residence time which is inversely proportional. It is also noticeable that when the speed of the mobile node is higher (V_{avg} = 10 m/sec) then the effect of γ over residence time is lesser as compared to speed. When mobility factor γ = 1, the mobile node travels in a straight line most of the time and hence residence time in communication area is lowest. Referring to (3), (7) and (9) the residence time in FF and RWP mobility models is inversely proportional to the speed of mobile node but residence time in FF model is inversely proportional to the double of speed of mobile node as compared to RWP model. Although, mobility factor (γ) and probability ρ_m have inverse effect over residence time in RWP model but these factor have value which is less than equal to one. So,

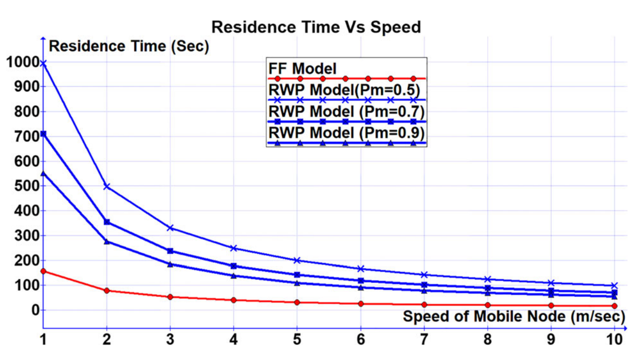

Fig. 4 Residence time versus speed of mobile node

the residence time of the mobile node is less in FF model as compared to RWP model.

Referring to Fig. 6, we have selected the speed of mobile node V_{avg} = 5 and 10 m/sec and communication range R = 100 m. The mobility factor (γ) and ρ_m vary from 0.1 to 1. It is obvious from this illustration that the residence time of the mobile node is maximum when $\gamma = \rho_m = 0.1$ and V_{avg} = 5 m/s in RWP mobility model but it is constant in FF mobility model for constant V and R. But when parameters γ, ρ_m, and V are increased then residence time decreases in RWP mobility model. This is due to the effect of these parameters over the residence time which is inversely proportional. It is also noticeable that when the speed of the mobile node is higher (V_{avg-} = 10 m/sec) and $\rho_m = \gamma$=1 then the residence time in FF and RWP mobility models is almost equal. It is obvious from Figs. 4, 5, 6, 7 that when mobile node follows zig-zag type of motion then residence time is more even through the speed varies. The radius of the communication (R) is also crucial in deciding the residence time of the node. Increasing the radius can enhance the residence time more in zig-zag time of motion.

3.2 Failure of fingers and life span of a node

MP2P systems are distributed systems and there is no central entity or server to control the system. Participating nodes are autonomous but cooperation from each node is desirable. Nodes are supposed to share their resources at their wish. We assume that topology formed by the participating mobile nodes is tightly governed by ring topology. The rate of failure $\lambda_f$of a node in MP2P system depends upon CR (Churn Rate) and λ_m of the node. So, we defined the rate of failure as follows.

$$\lambda_f = \alpha CR + (1 - \alpha)\lambda_m \tag{10}$$

where $0 \leq \alpha \leq 1$ is a tuning parameter.

We defined stabilization factor (S_f) as the ratio of rate of failure and rate of stabilization (λ_s) as follows.

$$S_f = \frac{\lambda_f}{\lambda_s} \tag{11}$$

We observed the following conclusions depending upon the values of S_f-

(1) If S_f = 1then it reflects the optimal stabilization,
(2) If $S_f > 1$ then it reflects over stabilization, and
(3) If $S_f < 1$ then it reflects under stabilization.

The failure of finger table is dependent on failure of fingers. The failure of fingers in the finger table depends upon the mobility rate (λ_m) and churn rate (CR). Suppose there are m fingers in the finger table then failure rate of the finger table is defined as follows.

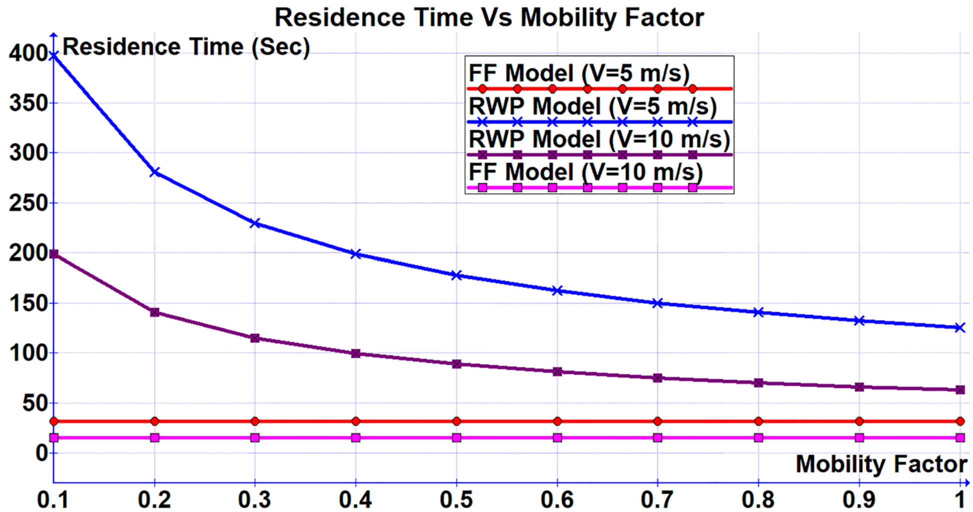

Fig. 5 Residence time versus mobility factor (γ)

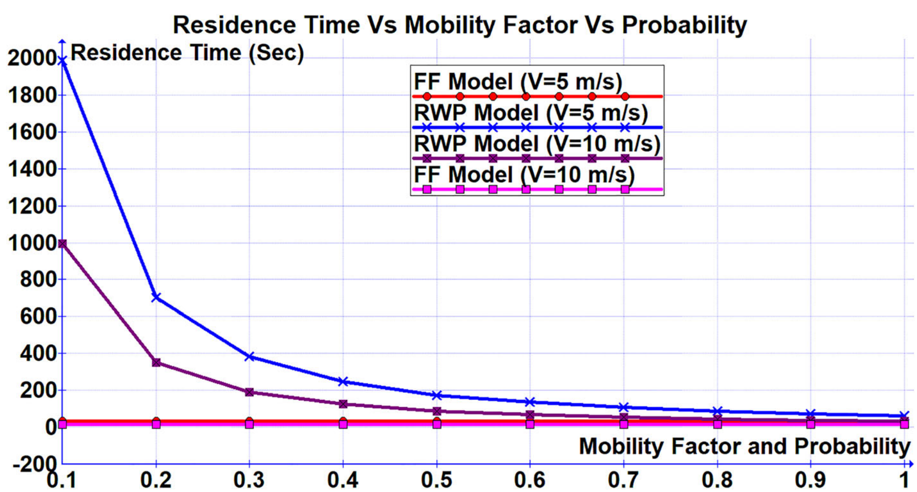

Fig. 6 Residence time versus mobility factor (γ) versus probability (ρ_m)

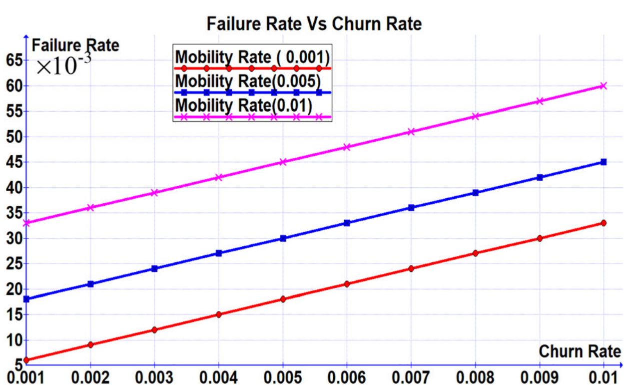

Fig. 7 Failure rate (λ_F) versus Churn rate (CR)

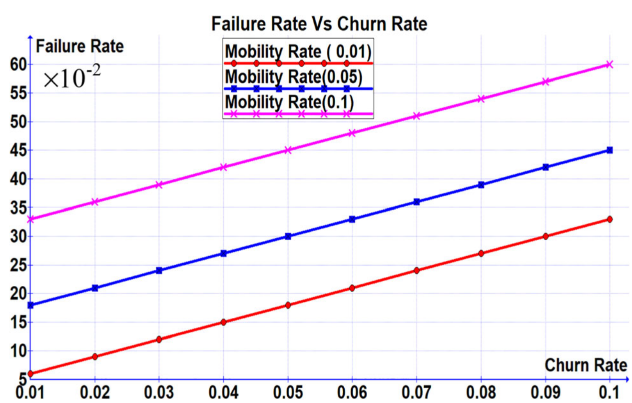

Fig. 8 Failure rate (λ_F) versuss Churn rate (CR)

$$\lambda_F = m\lambda_f = m\{\alpha CR + (1-\alpha)\lambda_m\} \tag{12}$$

Stabilization of the finger table is defined over failure rate and stabilization rate as follows.

$$S_{ft} = \lambda_F - m\lambda_s = m[\{\alpha CR + (1-\alpha)\lambda_m\} - \lambda_s] \tag{13}$$

If $S_{ft} \leq 0$ then we consider the fingers' stabilization up to mark.

In Figs. 7 and 8, failure rate Vs CR (churn rate) has been illustrated. The CR varies from 0.001 to 0.1. The other parameters α = 0.5, and λ_m is selected as 0.001, 0.005, 0.01, 0.05 and 0.1. The number of chords in a finger table, m = 6. The value of $\alpha = 0.5$ indicates 50% weighted for CR and λ_m each. The value CR = 0.1 indicates one disappearance in 10 unit time. Similarly, $\lambda_m = 0.05$ indicates 5 number of crossings of communication range in 100 unit time. Referring to Fig. 7, CR varies from 0.001 to 0.01. When CR = 0.001 and $\lambda_m = 0.001$ then failure rate, $\lambda_F = 6 \times 10^{-3}$ i.e. 6 failures per 1000 unit time. But as CR and λ_m are increased then λ_F is also increased. Referring to Fig. 8, CR varies from 0.01 to 0.1. When CR = 0.1 and $\lambda_m = 0.1$ then $\lambda_F = 0.6 \times 10^{-2}$. So, the effect of churn rate and mobility rate of mobile node is proportional over the failure rate (Table 1).

In Figs. 9 and 10, failure rate Vs tuning factor, CR (churn rate) and mobility rate has been illustrated. Referring to Fig. 9, the tuning factor varies from 0.1 to 1 and m = 6. The mobility rate (λ_m) = 0.001 which indicates less mobility rate. The variation in tuning factor indicates the change in the weighted given to CR or λ_m. The CR has been considered as 0.005 and 0.01. It is clear from this illustration that increase in the tuning factor shows the increase in the failure rate even if the CR rate is constant. This means the tuning factor should be selected judiciously. If CR is most dominant factor than tuning factor should be kept higher otherwise lower. Referring to Fig. 10, failure rate has been illustrated while varying CR and λ_m equally from 0.01 to 0.1. The other parameters are selected as $\alpha = 0.5$ and m = 6. The tuning factor $\alpha = 0.5$ indicates 50% weighted for CR and λ_m each. It is obvious from this illustration that failure rate increases as CR and

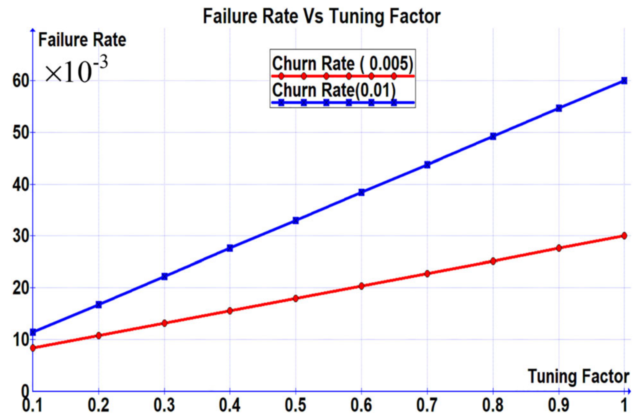

Fig. 9 Failure rate (λ_F) versus tuning factor (α)

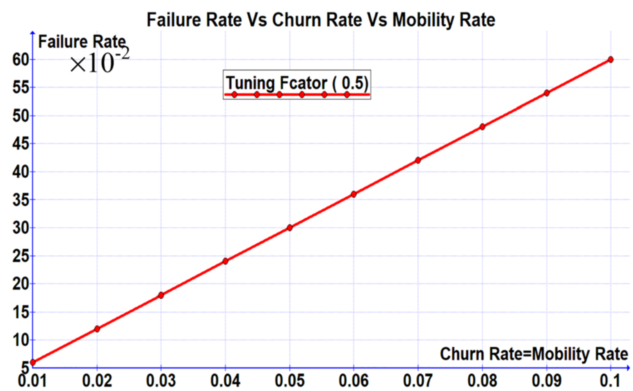

Fig. 10 Failure rate (λ_F) versus Churn rate versus mobility rate

Table 1 Parameters

S. No.	Parameter	Description	Value
1	λ_j	Rate of joining of nodes	0.1–10
2	λ_f	Rate of failure per node	0.1–10
3	λ_F	Rate of failure per Finger Table	
4	λ_s	Rate of stabilization per node	
5	λ_m	Mobility rate per node	0.001–0.1
6	λ_{sr}	P2P session arrival rate per node	
7	ρ_s	Probability of P2P session arrival between two consecutive boundary crossing	0.01–1
8	ρ_m	Probability of crossing $i \geq 1$ number of boundaries between two consecutive Mobile P2P sessions	0.01–1
9	C_{st}	Total finger table stabilization Cost per node	
10	V_{avg}	Average Velocity of a Node (m/sec)	1–10 m/sec
11	V_{max}, V_{min}	Maximum and Minimum Velocity (m/sec) of a Node	
12	C_t	Single finger table stabilization cost in sec	1 s
13	N	Average number of nodes in MP2P network	2–50
14	R	Average Radius of P2P communication	1–100 m
15	SMR	Session-to-Mobility Ratio	0.1–1
16	L_{tr}	Transition Length in meter	
17	W_{max}, W_{min}	Maximum and Minimum Bandwidths in mb/sec	2–15 mb/sec

λ_m increase. In Figs. 7, 8, 9, 10, the failure rate of a node has been illustrated. It is dependent on CR and mobility rate. If CR and mobility rate are increasing then failure rate is also increasing.

The life span (L_t) of a node follows Poisson distribution with mean $^1/_{\lambda_f}$. So, let $L_t = \frac{\eta}{\lambda_f}$ where $0 < \eta \leq 1$ is a tuning factor. Let the expected life time of a node in MP2P network is E(L_t) in sec, i.e. $E(L_t) = \frac{\eta}{\lambda_f} = n_1$ where n is the number of joining for node and ρ_1 is the probability of anode to be alive in the network. So, $\rho_1 = \frac{\eta}{n\lambda_f}$. We assumed that the joining or leaving processes of mobile nodes are independent and these don't affect each other. Life span of each mobile node in MP2P network follows the Poisson's distribution. So, we define the probability of a node's life span as k (in sec) as per Poisson distribution.

$$\begin{aligned}\rho_1(x = k) &= \lim_{n\to\infty} \binom{n}{k} \left(\frac{\eta}{n\lambda_f}\right)^k \left(1 - \frac{\eta}{n\lambda_f}\right)^{n-k} \\ &= \lim_{n\to\infty} \frac{n!}{(n-k)!k!n^k} \left(\frac{\eta}{\lambda_f}\right)^k \left(1 - \frac{\eta}{n\lambda_f}\right)^{n-k} \\ &= \left(\frac{\eta}{\lambda_f}\right)^k \frac{1}{k!} \lim_{n\to\infty} \frac{n!}{(n-k)!n^k} \left(1 - \frac{\eta}{n\lambda_f}\right)^{n} \\ &\left(1 - \frac{\eta}{n\lambda_f}\right)^{-k} \approx \frac{\eta^k e^{-\eta/\lambda_f}}{\lambda_f^k k!}\end{aligned} \tag{14}$$

The PDF (Probability Density Function) of the probability for life span of a node defined in (9) is given as follows.

$$PDF(\rho_1(\mathrm{x} > \mathrm{k})) = 1 - \sum_{i=0}^{k} \frac{\eta^i e^{-\eta/\lambda_f}}{\lambda_f^i i!} \tag{15}$$

The life span of a node with respective probability has been shown in Fig. 11. The failure rate (λ_f) is taken as 0.1 per minute which means expected life span of the node has been considered as 10 min. The life span of the node varies from 1 to 20 min and corresponding probability has been illustrated. The value of tuning factor (η) is considered as 1 for convenience. It is obvious from the illustration that as life span decreases or increases with respect to the expected value (10 Min) then corresponding probability decreases. The value of η is selected as per the values of CR and λ_m and it is considered nearby one. But sometimes nodes are disconnected due to other reasons. In such conditions, value η is taken less.

3.3 Finger table stabilization cost

As reported in [17] that nodes arrivals rate in the MP2P networks follow Poisson process with constant rate

$$\lambda_j = \frac{Average\ Number\ of\ Nodes}{Mean\ Node's\ Life\ Time} = \frac{N}{E(L_t)} = \frac{N\lambda_f}{\eta}.$$

Thus $\lambda_j = \frac{N}{E(L_t)} = \frac{N\lambda_f}{\eta}$. So, the probability ρ_2 of k nodes arrival per unit time is defined below.

$$\rho_2(\mathrm{x} = \mathrm{k}) = \frac{\lambda_j^k e^{-\lambda_j}}{k!} = \frac{\left(\frac{N\lambda_f}{\eta}\right)^k e^{-\left(\frac{N\lambda_f}{\eta}\right)}}{k!} \tag{16}$$

We assume that stabilization rate is same as failure rate as defined in (10) and a node crosses the boundary of MP2P communication i number of times between two consecutive MP2P sessions and newly arrived nodes per unit time as defined in (16) are equally distributed among total number of nodes (N). So, the stabilization cost (C_{st} in sec) per unit time is defined as follows.

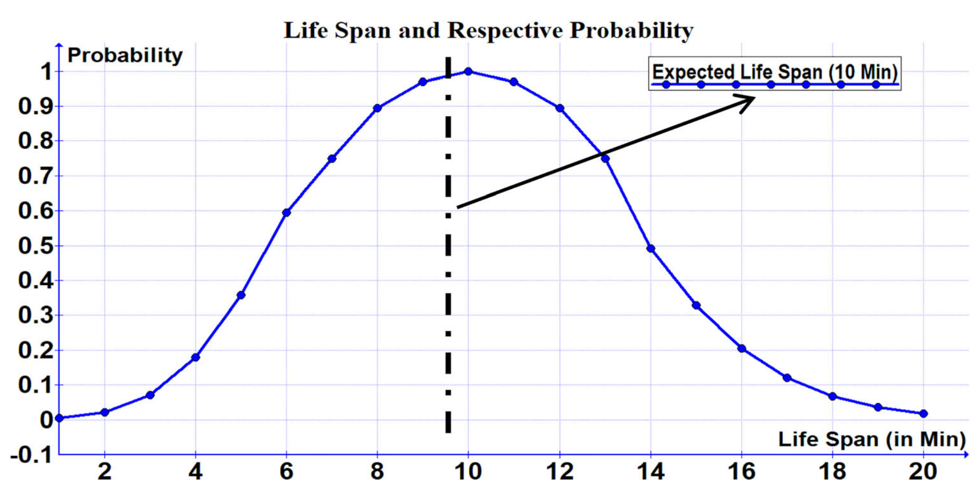

Fig. 11 Node's life span and respective probability

$$
\begin{aligned}
C_{st} &= \sum_{i=1}^{\infty} i\rho_m m\{\alpha CR + (1-\alpha)\lambda_m\}C_t \\
&\quad + \frac{C_t}{N}\sum_{k=1}^{\infty} k\rho_m \frac{\left(\frac{N\lambda_f}{\eta}\right)^k e^{-\left(\frac{N\lambda_f}{\eta}\right)}}{k!} \\
&= m\{\alpha CR + (1-\alpha)\lambda_m\}C_t \sum_{i=1}^{\infty} i\rho_s\left(\frac{1}{1+SMR}\right)^i \\
&\quad + \lim_{k\to\infty}\frac{\left(\frac{N\lambda_f}{\eta}\right)^k}{k!}\frac{C_t}{N}\sum_{k=1}^{\infty} k\rho_m e^{-\left(\frac{N\lambda_f}{\eta}\right)} \\
&= m\{\alpha CR + (1-\alpha)\lambda_m\}C_t \frac{SMR}{1+SMR}\sum_{i=1}^{\infty} i\left(\frac{1}{1+SMR}\right)^i \\
&\quad + \frac{C_t}{N}e^{-\left(\frac{N\lambda_f}{\eta}\right)} \times \frac{SMR}{1+SMR}\sum_{k=1}^{\infty} k\left(\frac{1}{1+SMR}\right)^k \\
&= \frac{m\{\alpha CR + (1-\alpha)\lambda_m\}C_t + e^{-\left(\frac{N\lambda_f}{\eta}\right)}\frac{C_t}{N}}{SMR}
\end{aligned} \tag{17}
$$

Finger table stabilization cost (C_{st}) has been illustrated in Figs. 12, 13, 14 and 15 while varying CR (Churn Rate), node arrival rate (λ_j), and SMR (Session-to-Mobility Ratio). Other parameters, SMR = 0.5, $\alpha = 0.5$, $\eta = 1$, $C_t = 1$ (sec), m = 6, and N = 50. It means there are 50 nodes in communication area and 6 chords in the finger table maintained by each node. The value of η is considered as 1 to keep the analysis simple and value of $\alpha = 0.5$ indicates equal weightage for CR and λ_m in calculation of failure rate. Here, the value $0 < SMR \leq 1$ and thus SMR is considered in medium range. Referring to Fig. 12, CR varies from 0.01 to 0.1 and stabilization costs for mobility rates 0.01, 0.05 and 0.1 have been illustrated. It is obvious from illustration that if CR and λ_m are increasing then C_{st} is also increasing. The stabilization costs in respect of above parameters' value are expressed as, $C_{st} = 6CR + 0.06 + \frac{1}{25e^{25CR+.25}}$;$C_{st} = 6CR + 0.3 + \frac{1}{25e^{25CR+.25}}$

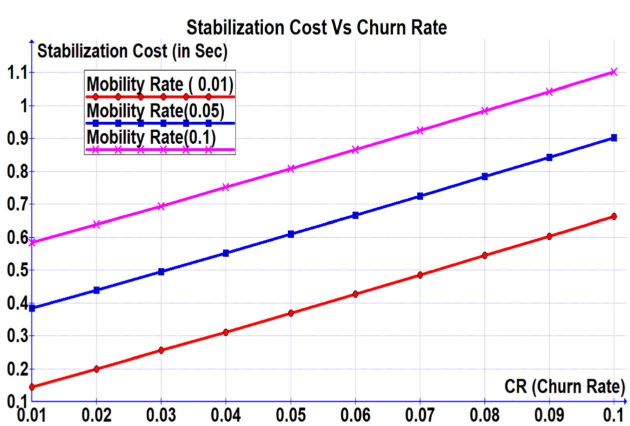

Fig. 12 Finger table stabilization cost and churn rate

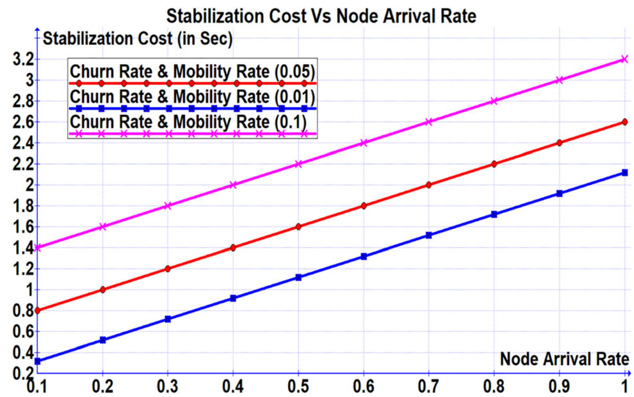

Fig. 13 Finger table stabilization cost and node arrival rate

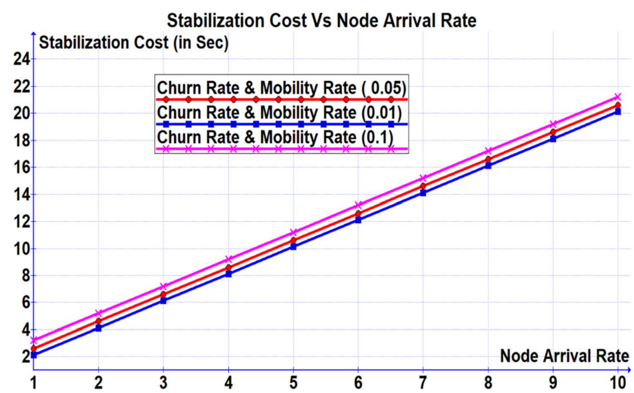

Fig. 14 Finger table stabilization cost and node arrival rate

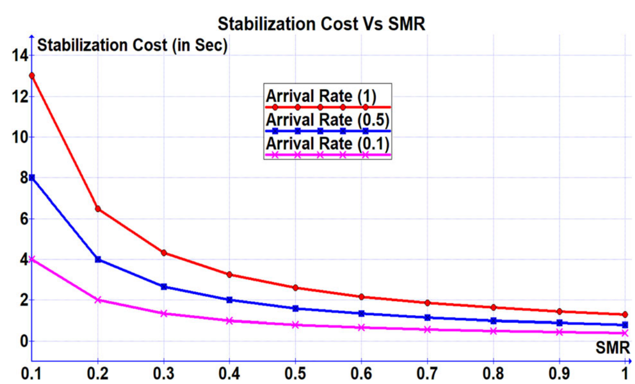

Fig. 15 Finger table stabilization cost and session-to-mobility ratio

and $C_{st} = 6CR + 0.5 + \frac{1}{25e^{25CR+.25}}$ for $\lambda_m = 0.01$, $\lambda_m = 0.05$ and $\lambda_m = 0.1$ respectively. Referring to Figs. 13 and 14, stabilization cost while varying node arrival rate has been illustrated. The node arrival rate has been considered per node and it varies from 0.1 to 10. The value of $\lambda_j = 0.5$ means 5 new nodes arrival per 10 unit time. The three different values 0.01, 0.05, and 0.1 for CR and λ_m have been considered. It is obvious from illustration that stabilization cost increases in proportionate with CR, λ_m, and λ_j.

Referring to Fig. 15, stabilization cost while varying the SMR has been illustrated. Other parameters are taken as, CR = λ_m = 0.5, α = 0.5, η = 1, C_t = 1 (sec), m = 6 and N = 50. The nodes' arrival rate is taken as 0.1, 0.5 and 1. When SMR is low, it means mobility rate of node is higher than stabilization cost. When node's arrival rate is higher than stabilization cost is higher also. So, when SMR = 0.1 and arrival rate is 1 then stabilization cost is 13 s whereas stabilization cost is 4 s when SMR = 0.1 and arrival rate is 0.1. So, it is obvious from this illustration that stabilization cost is proportional to arrival rate but reciprocal to SMR.

Finger table stabilization is a Poisson process and expected stabilization factor S_f = 1 for optimal stabilization. We assumed that stabilization of finger tables is independent process for all nodes in the MP2P network and it is a discrete event over time period. Let the expected value of stabilization factor S_f = β=1 for t time period. The expected value,$E(x) = \beta = \rho_3 \times n$ so, $\rho_3 = \beta/n$ where n is the number of stabilizations. We defined the probability of stabilization factor for k value as per Poisson distribution.

$$\begin{aligned}\rho_3(\mathrm{x}=\mathrm{k}) &= \lim_{\mathrm{n}\to\infty}\binom{n}{k}\left(\frac{\lambda_f}{n\lambda_s}\right)^k\left(1-\frac{\lambda_f}{n\lambda_s}\right)^{n-k}\\ &= \lim_{\mathrm{n}\to\infty}\frac{n!}{(n-k)!k!}\left(\frac{\lambda_f}{n\lambda_s}\right)^k\left(1-\frac{\lambda_f}{n\lambda_s}\right)^n\left(1-\frac{\lambda_f}{n\lambda_s}\right)^{-k}\\ &= \left(\frac{\lambda_f}{\lambda_s}\right)^k\frac{1}{k!}\lim_{\mathrm{n}\to\infty}\frac{n!}{(n-k)!n^k}\\ &\quad\left(1-\frac{\lambda_f}{n\lambda_s}\right)^n\left(1-\frac{\lambda_f}{n\lambda_s}\right)^{-k}\approx\left(\frac{\lambda_f}{\lambda_s}\right)^k\frac{1}{k!}\end{aligned} \tag{18}$$

For optimal stabilization of the finger table, x = k=1 then

$$\frac{\lambda_f}{\lambda_s}\approx 1 \tag{19}$$

It means that stabilization rate should be equal to failure rate for optimal stabilization.

3.4 Intermittent bandwidth and its effect

In MP2P networks, intermittent bandwidth is a challenge. The available bandwidth depends upon many factors like uploading capacity of equipment, distance from feeder node, restricted upload bandwidth, etc. Sometime, mobile user restricts the upload bandwidth to a maximum limit. We assume that W_{min} and W_{max} are minimum and maximum bandwidths respectively of mobile node during certain time period and these are independent and identically distributed. The available bandwidth varies between W_{min} and W_{max}. We suppose at particular time, the available bandwidth is W_{avl} such that $W_{min} \le W_{avl} \le W_{max}$. Further we assume two nodes are static while communicating but nodes are mobile then these are in communication range. W_{avl} is continuous variable and distributed over W_{min} and W_{max}. The available bandwidth W_{avl} follows Gamma distribution over W_{min} and W_{max}. We define the probability of available bandwidth W_{avl} during specific time period as follows.

$$\begin{aligned}&\rho_3(\lceil W_{avl}\rceil \mid \lceil W_{max}\rceil, \lceil W_{min}\rceil)\\ &\quad= \frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}\lceil W_{avl}\rceil^{\lceil W_{max}\rceil-1}e^{\lceil -W_{min}\rceil\lceil W_{avl}\rceil}}{(\lceil W_{max}\rceil-1)!}\end{aligned} \tag{20}$$

where $W_{avl} \ge 0$, W_{min}, $W_{max} > 0$The mean or expected value of the available bandwidth as define in (20) is obtained as follows.

$$\begin{aligned}E(\lceil W_{avl}\rceil) &= \int_{-\infty}^{\infty}\lceil W_{avl}\rceil\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}\lceil W_{avl}\rceil^{\lceil W_{max}\rceil-1}e^{-\lceil W_{min}\rceil\lceil W_{avl}\rceil}}{R^2\lceil W_{max}\rceil!}d\lceil W_{avl}\rceil\\ &=0+\int_{0}^{\infty}\lceil W_{avl}\rceil\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}\lceil W_{avl}\rceil^{\lceil W_{max}\rceil-1}e^{-\lceil W_{min}\rceil\lceil W_{avl}\rceil}}{(\lceil W_{max}\rceil-1)!}d\lceil W_{avl}\rceil\\ &=\frac{\lceil W_{max}\rceil}{\lceil W_{min}\rceil}\end{aligned} \tag{21}$$

We define the variance of W_{avl} as follows.

$$Var(W_{avl}) = E\left(W_{avl}^2\right) - (E(W_{avl}))^2 \tag{22}$$

$$\begin{aligned}&= \int_{-\infty}^{\infty}\lceil W_{avl}\rceil^2\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}\lceil W_{avl}\rceil^{\lceil W_{max}\rceil-1}e^{-\lceil W_{min}\rceil\lceil W_{avl}\rceil}}{(W_{max}-1)!}\\ &\qquad d\lceil W_{avl}\rceil - \frac{\lceil W_{max}\rceil^2}{\lceil W_{min}\rceil^2}\\ &=0+\int_{0}^{\infty}\lceil W_{avl}\rceil^2\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}\lceil W_{avl}\rceil^{\lceil W_{max}\rceil-1}e^{-\lceil W_{min}\rceil\lceil W_{avl}\rceil}}{(\lceil W_{max}\rceil-1)!}\\ &\qquad d\lceil W_{avl}\rceil - \frac{\lceil W_{max}\rceil^2}{\lceil W_{min}\rceil^2}\\ &=\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}}{\lceil W_{max}\rceil!}\int_{0}^{\infty}\lceil W_{avl}\rceil^2\lceil W_{avl}\rceil^{\lceil W_{max}\rceil-1}e^{-\lceil W_{min}\rceil\lceil W_{avl}\rceil}d\lceil W_{avl}\rceil\\ &\qquad-\frac{\lceil W_{max}\rceil^2}{\lceil W_{min}\rceil^2}\\ &=\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}}{(\lceil W_{max}\rceil-1)!}\int_{0}^{\infty}\lceil W_{avl}\rceil^{(\lceil W_{max}\rceil+2)-1}e^{-\lceil W_{min}\rceil\lceil W_{avl}\rceil}d\lceil W_{avl}\rceil\\ &\qquad-\frac{\lceil W_{max}\rceil^2}{\lceil W_{min}\rceil^2}\\ &=\frac{\lceil W_{min}\rceil^{\lceil W_{max}\rceil}(\lceil W_{max}\rceil+1)!}{(\lceil W_{max}\rceil-1)!\lceil W_{min}\rceil^{\lceil W_{max}\rceil+2}}-\frac{\lceil W_{max}\rceil^2}{\lceil W_{min}\rceil^2}\\ &=\frac{\lceil W_{max}\rceil(\lceil W_{max}\rceil+1)}{\lceil W_{min}\rceil^2}-\frac{\lceil W_{max}\rceil^2}{\lceil W_{min}\rceil^2}=\frac{\lceil W_{max}\rceil}{\lceil W_{min}\rceil^2}\end{aligned} \tag{23}$$

The available bandwidth and respective probability has been illustrated in Fig. 16. The minimum and maximum

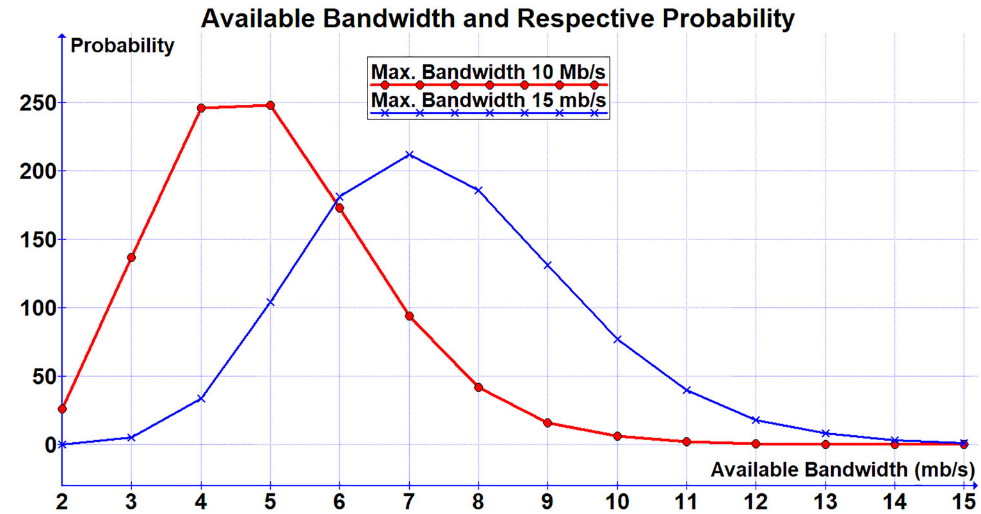

Fig. 16 Available bandwidth and respective probability

bandwidths are considered as $W_{min} = 2$ mb/s and $W_{max} = 15$ mb/s. The available bandwidth (W_{avl}) is continuous distributed parameter over W_{max} and W_{min}. Further we assume that $W_{avl} \geq 0$ and W_{max}, $W_{min} > 0$. The available bandwidth W_{avl} follows Gamma distribution and probability of available W_{avl} is expressed in (18). In structured MP2P communication two nodes are communicated with each other for shorter time period when nodes are in communication range. It is also noticeable that available bandwidth for MP2P communication is very limited and intermittent. Referring to Fig. 16, the available bandwidth W_{avl} varies from 2 to 15 mb/s and respective probability has been shown. When $W_{max} = 10$ mb/s and $W_{min} = 2$ mb/s then $\rho_3(2|10, 2) = 0.026$, $\rho_3(5|10, 2) = 0.248$, and $\rho_3(15|10, 2) \approx 0.00001$. When $W_{max} = 15$ mb/s and $W_{min} = 2$ mb/s then $\rho_3(2|10, 2) = 0.0001$, $\rho_3(5|10, 2) = 0.104$, $\rho_3(7|10, 2) = 0.212$ and $\rho_3(15|10, 2) \approx 0.001$. It is obvious from this illustration that probability is higher when available bandwidth is in the average range of W_{max} and W_{min}.

The available bandwidth and respective probability has been illustrated in Fig. 16. The minimum and maximum bandwidths are considered as $W_{min} = 2$ mb/s and $W_{max} = 15$ mb/s. The available bandwidth (W_{avl}) is continuous distributed parameter over $W_{max}$and W_{min}. Further we assume that $W_{avl} \geq 0$ and W_{max}, $W_{min} > 0$. The available bandwidth W_{avl} follows Gamma distribution and probability of available W_{avl} is expressed in (18). In structured MP2P communication two nodes are communicated with each other for shorter time period when nodes are in communication range. It is also noticeable that available bandwidth for MP2P communication is very limited and intermittent. Referring to Fig. 16, the available bandwidth W_{avl} varies from 2 to 15 mb/s and respective probability has been shown. When $W_{max} = 10$ mb/s and $W_{min} = 2$ mb/s then $\rho_3(2|10, 2) = 0.026$, $\rho_3(5|10, 2) = 0.248$, and $\rho_3(15|10, 2) \approx 0.00001$. When $W_{max} = 15$ mb/s and $W_{min} = 2$ mb/s then $\rho_3(2|10, 2) = 0.0001$, $\rho_3(5|10, 2) = 0.104$, $\rho_3(7|10, 2) = 0.212$ and $\rho_3(15|10, 2) \approx 0.001$. It is obvious from this illustration that probability is higher when available bandwidth is in the average range of W_{max} and W_{min}.

4 Conclusion

We have presented a detailed analytical modelling of the performance of Chord or Chord based protocols in wireless environments like MANETs, WMNs, WSNs, VANETs, WLAN, WMAN etc. in respect of various parameters such as mobility rate of users, churn rate of nodes, intermittent bandwidth, expected life span of a node, stabilization cost, SMR etc. It has been observed that life span of a mobile node is inversely proportional to mobility rate and churn rate. When user follows longer path then residence time in a communication area is less as compared to zig-zag motion restricted to certain area. Failure rate of node is proportional to its mobility rate and churn rate. We have proposed two mobility models namely FF and RWP as per the mobility pattern of the mobile users. The finger table stabilization cost is dependent upon mobility rate, churn rate and arrival rate of the nodes. When these parameters increase then stabilization cost increases in order to keep the finger table updated. The stabilization cost is inversely proportional to the SMR. The available bandwidth has higher probability to be in the average range of minimum and maximum bandwidths. Stabilization of finger table is necessary to keep information updated and reduce failure rate. Stabilization rate must be equal to the failure rate for optimal stabilization of the finger table. The proposed work is useful for analysing the performance of the Chord-based protocols applicable in different wireless environments like MANETs, WMNs, WSNs, VANETs, WLAN, WMAN etc. The free riding behaviour of participating nodes has not been considered in proposed work in performance analysis with respect to expected life span of a node, stabilization cost, and SMR which can be considered for further study.

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