Stability of Inter domain Routing Protocol with Regressive Peak Contour

Bhavneet Kaur[1], Karanjeet Singh Kahlon[2] and Sandeep Sharma[3]

[1]**Department of Computer Science and Engineering, Guru Nanak Dev University Amritsar, Punjab, India**

[2]**Department of Computer Science and Engineering, Guru Nanak Dev University Amritsar, Punjab, India**

[3]**Department of Computer Science and Engineering, Guru Nanak Dev University Amritsar, Punjab, India**

Abstract

Safety of BGP and its convergence does not include stable routing in terms of various operational features of BGP such as route flap damping, MRAI timers etc. This paper shows these features can cause router to send pseudo advertisement of less preferred path and in a simple network scenario the pseudo advertisement of less preferred paths can result in situation where it can take more time to converge to stable routing. A model PRP is discussed so that impact of pseudo advertisement on BGP safety can be examined with necessary and sufficient condition.

Keywords: *SPP, SPVP, MRAI, RFD, dispute wheel, dispute reel.*

1. Introduction

The BGP (border gateway protocol) ([5], [13], [15]) is the inter-domain routing protocol in internet. In it different ASes (autonomous systems) can exchange information regarding the reachability with each other. Each ASes maintains its own independent routing decisions through which they can exchange reachability information. This flexibility of independent routing decisions may result in steady cycles. These cycles increases the number of BGP path renewals packets which leads to increased traffic in network.

Previous researches have shown that how routing decisions made by independent ASes leads to cycles [8]-[14]. Most of these researches have used a theoretical model-SPVP (Simple Path Vector Protocol) ([7], [12]).This paper discusses PRP (Progressive Route Procedure) which captures the effect of various local operational features of BGP (RFD, MRAI timer) on global convergence. A model RPC (Regressive Peak Contour) is proposed which shows safety of BGP.

1.1 Selection of less-preferred paths

Pseudo renewals are abrupt advertisement and withdrawals of paths. These renewals occur when router briefly advertise other recently available alternate paths to destination when higher ranked paths become unavailable. During this the router can select the less-preferred path. In order to enhance stability, scalability and decrease overhead routers often lead to pseudo renewals i.e. they delay the propagation of renewal information or they curb the visibility to alternate paths. There are other mechanisms that can cause pseudo renewals. These are: Route Flap Damping (RFD) ([3], [6]) minimize the propagation of flapping paths (i.e. a path that repeatedly becomes unavailable, then available) across an internetwork. This leads to selection of less-preferred path. Minimum Route Advertisement Interval (MRAI timer) **(**[2], [5]) determines the minimum time between advertisements of paths to a particular destination. Increasing this time can cause router to select less-preferred path. The value of MRAI timer used in practice range between 0 and 30 seconds. All the pseudo renewals generated by above factors will have following characteristics: a) Pseudo renewals are transmitted for only short period of time, only when higher rank path is unavailable. b) Pseudo renewals can select path from list of recently available paths.

1.2 Safety conditions of PRP

The conditions under which SPVP was safe apply even to PRP also i.e. PRP is safe if dispute wheel is absent.

Review of the sufficient condition of safety under filtering establishes that absence of dispute reel structure does not guarantee safety of network under filtering. A modified structure two-third reel shows the safety of PRP under filtering. This paper proposes a new structure RPC (Regressive Peak Contour) which will act as both necessary and sufficient condition for PRP safety.

2. PRP: Model with Pseudo Renewals

To study the impact of pseudo renewals on network, Progressive Route Procedure (PRP) model is discussed. This model transmits the old information about paths in form of pseudo renewals. PRP uses the SPP framework to show formation of cycles with pseudo renewals.

2.1 Stable path problem (SPP)

The stable path problem (SPP) ([7],[12]) consists of a simple undirected graph G= (V, E) where V is a vertex set and E is edge set. Node 0 is assumed to be destination node which all others nodes try to reach. Each node v ε V has its own set P^v of permitted paths to origin and each path have a ranking function λ^v. If P_1, P_2 ε P^v and $\lambda^v(P_1) < \lambda^v(P_2)$ then node v will prefer P_2 over P_1. Solution to SPP is a path assignment π that maps each node v ε V to path $\pi(v)$ ε P^v. the path assignment π is stable at node v if $\pi(v)$ = best (choices (π, v), v) where:

$$\text{Choices } (\pi,v) = \begin{cases} \{(v\ u)\pi(u) \mid (v,u) \varepsilon E\} \cap P^v & v \neq 0 \\ \{\phi\} & \text{otherwise} \end{cases}$$

If W is subset of P^v such that each path in W have distinct next hop then best path in W is defined as:

$$\text{best } (W,v) = \begin{cases} P \ \varepsilon \ W \text{ with max } \lambda^v \\ \phi \quad \text{otherwise} \end{cases}$$

2.2 Framework used in PRP

The PRP algorithm uses following framework:

- Current time of global clock is denoted by T.
- The internal state of node ‘a’ consists of following: π(a) denotes allocated path which represents the most preferred path, NODE_INFO(a←d) maintained by node ‘a’ contains list of most recently available information received from node ‘d’, LATEST(a) contains all paths that node ‘ a’ has had recently available, ST(a) denotes stable time of node ‘a’.
- A fixed constant δ is used. It serves as an upper bound on communication delay caused by pseudo renewals.

The stability of node is determined by following property: the node ‘a’ is stable if T≥ST(a) otherwise it is not stable. If node ‘a’ is stable then the neighbours of node ‘a’ will learn the accurate most recent path π(a). If node is not stable then neighbours of node ‘a’ will receive old information which will consists of any one path from LATEST(a).

2.3 Progressive Route Procedure (PRP)

The swapping of vital route information is done by provocation of the edges. More than one edge can be stimulated at same time. When edge (d,a) stimulates, following algorithm is executed.

Algorithm:

1. All previous information in NODE_INFO is transferred to NODE_INFO (a←d).
2. If node‘d’ is stable i.e. T≥ST (d) then NODE_INFO (a←d) :=(ad)π(d).
3. If node’d’ is not stable then select some path P i.e. Pε{LATEST(d)Uϕ} and update NODE_INFO i.e. NODE_INFO(a←d):=(ad)P.
4. Update the list of latest paths available. If NODE_INFO(a←d)≠ old-NODE_INFO then add NODE_INFO(a←d) to LATEST(a). Also remove old-NODE_INFO from LATEST(a) at time T+δ.
5. Now determine best path available to node a. If π(a)≠best(NODE_INFO,a) then π(a):= best(NODE_INFO,a). And set ST(a):=T+δ.

When node‘d’ is stable then step-2 is executed. The structure NODE_INFO(a←d) is updated with most recent information from node ‘d’. If node‘d’ is not stable then step-3 is executed and node gets old information which may consist of path revocation or advertisement of path that was recently available at node‘d’. Step-4 updates the list of available paths. New paths are added and those paths are removed which become unavailable at time T. Step-5 determines the best path available to node ‘a’ which contains the consistent information. If there is change in route then π(a) is updated according to that information and node is marked as unstable for time period δ.

3. Secure BGP with pseudo renewals

This will be established that no dispute wheel condition which was sufficient for BGP safety in SPVP model, still hold for safety with pseudo renewals in PRP. Also it is shown that absence of dispute reel is not sufficient condition for safety under filtering with pseudo renewals.

3.1 Secure Dispute Wheel:

Dispute wheel is classical result of Griffin ([1], [7], [9], [12]) which shows the safety of BGP in SPVP model. BGP is safe if there is no dispute wheel and this condition holds for PRP also. A dispute wheel is W= (U, Q, R) of size k is a set nodes U= $\{u_0, u1,\ldots\ldots.,u_{k-1}\}$ and set of paths $Q=\{Q_0,Q_1,\ldots\ldots.,Q_{k-1}\}$ and $R=\{R_0,R_1,\ldots\ldots..,R_{K-1}\}$ such that following conditions hold:

i. Q_i is a path from u_i to the origin.
ii. R_i is a path from u_i to u_{i+1}.
iii. $Q_i \varepsilon P^u_i$ and $R_iQ_{i+1} \varepsilon P^u_i$.
iv. $\lambda^u_i(Q_i) \le \lambda^u_i(R_iQ_{i+1})$.

To show safety of PRP under dispute wheel, it is needed to prove the following statement: "PRP exponent with no dispute wheel is safe". Absence of dispute wheel only guarantees the sufficient condition for safety but not the necessary condition in both SPVP and PRP. This means that dispute wheel can occur in safe exponents of routing problem.

3.2 Secure Dispute Reel:

Prior work by Cittandini [10] proved that exponents that do not contain a dispute reel are safe under filtering and if an exponent contains a dispute reel, then there exist a filtering that allow cycles. The dispute reel is a dispute wheel which satisfies following conditions:

i. Pivot vertices appear in exactly three paths.
ii. Spoke and rim paths do not intersect.
iii. Spoke path form a tree.

Above results by Cittandini does not hold in case of pseudo renewals. If PRP has no dispute reel then it does not guarantee safety under filtering with pseudo renewals. This can be shown in following way: consider the network that appears in original work of Cittadini [10] as shown in Fig.1 where it is proved that network is safe because it does not contain dispute reel but this section will show that this network contains a cycle.

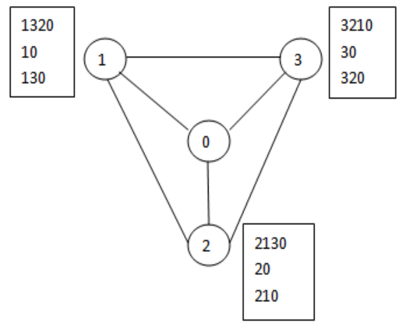

Fig.1. Network does not have reel but it has cycles [10]

Table 1. Cycles in absence of dispute reel

Nodes, Edges Stimulated	Information Transferred	Path Selected(π)
		(10,20,30)
node=1	dropped path=10 new selected path=130	(130,20,30)
node=2	dropped path=20 new selected path=210	(130,210,30)
node=3	dropped path=30 new selected path=320	(130,210,320)
node=1	dropped path=130 new selected path=1320	(1320,210,320)
node=2	dropped path=210 new selected path=2130	(1320,2130,320)
node=3	dropped path=320 new selected path=3210	(1320,2130,3210)
node=1	dropped path=1320 new selected path =10	(10,2130,3210)
node=2	dropped path=2130 new selected path =20	(10,20,3210)
node=3	dropped path=3210 new selected path =30	(10,20,30)

From table 1 it is clear that cycle is formed that is initial state is reached again. This cycle has occurred in network which does not have dispute reel. And this cycle is valid under PRP. Hence it is proved that absence of dispute reel does not guarantee safety under filtering.

3.3 Mega-Reel:

A modified structure is introduced which will show safety of PRP under filtering. A mega-reel is a dispute wheel which satisfies the second and third condition of dispute reel:

i. Spoke and rim paths do not intersect.
ii. Spoke paths form a tree.

PRP is safe under filtering if and only if network does not contain mega-reel. This is established by proving following two implications:

3.3.1 If a PRP exponent P is not safe under filtering then it contains a mega-reel.

3.3.2 If a PRP exponent P contains a mega-reel then it is unsafe under filtering.

Before proving the above implications, it is needed to describe the notation that is used in this section a **PRP measure period (MP)**. A PRP measure period MP=(π, I,ɤ) consists of a path allocation cycle $\pi= (\pi_1, I_1, ɤ_1)\rightarrow(\pi_2, I_2, ɤ_2)\rightarrow\ldots\ldots\ldots\ldots(\pi_k, I_k,ɤ_k)\rightarrow\pi_{k+1}$ where I is information and ɤ is edge provocation track. Pseudo advertisements do not depend on events that occur before PRP measure period. Also every node that is sending information modifies its selected path once during MP.

Let path (MP, u) be paths that node 'u' selects at some point in MP. Let St be set of static nodes which have static path allocation throughout MP. Let Vb be vibrating nodes. Following another implication is needed in proving above statements.

3.3.3 Let P ε P^v is used by node v ε Vb in MP. Then we can write P=QR where first node on path R is in Vb and all other next nodes are in St.

Proof of 3.3.1: This section proves that an unsafe exponent has a mega-reel.

Let MP=(π, I,ɤ) be well formed non-worthy period. Let U⊆ St be nodes that select a path from a set that contains static nodes. U is nonempty since there are vibrating nodes and when 3.3.3 is applied to one of them, it gives a node in U.

Now construct dispute wheel. Let u_0 be node in U. let $Q_0=(u_0 , w_0)Q'_0$ be path of u_0 such that w_0 ε St. Since w_0 does not transmit pseudo renewals in MP, then there exists only one such Q_0 which has lowest rank path in path (MP,u_0). Let H_0 ε nodes (MP, u_0) be highest rank path u_0 ever selects, then

$\lambda^{u0}(H_0) > \lambda^{u0}(Q_0)$. Using 3.3.3, it can be deduce that $H_0=R_0Q_1$ with $Q_1=(u_1 , w_1)Q'_1$ and u_1ε U. If this process is repeated a track(u_i) is established, which reverts back to u_0 since U is finite. Node u_i , spoke Q_i , and rim R_i form a dispute wheel.

Next it will be proved that above constructed dispute wheel also satisfies the conditions defined under new modified structure mega-reel.

Suppose that condition (i) is not satisfied and there exists a node u ε $Q_i \cap R_j$ i.e. u is a node which common between spoke and rim paths. It is known that u ε Q_i , u and rest of $Q_i[u]$ lie in St. Since fixed nodes cannot transmit pseudo renewals , so any recurring advertisement of route via u will end with Q[u].Then $R_j[u]$ must be prefix of $Q_i[u]$, which means that $R_j[u] \subseteq$ St but it is against the following condition which states that $R_j[u]$ end in $u_{j+1} \notin$ St.

Now suppose even (ii) condition is violated. There exists a spoke paths Q_i , Q_j ε Q and node v ε $Q_i \cap Q_j$

Such that $Q_i[v] \neq Q_j[v]$, then spoke paths does not form a tree.

Hence it is proved that any exponent that is not safe under filtering will have mega-reel.

Proof of 3.3.2 Suppose a mega-reel exist the first find the cause of cycle. For this find the path allocations that cause cycle and show provocation track that allows infinite alteration between these path allocations.

Suppose exponent E of SPP contains dispute wheel 'W'. E[W] is minimal exponent which contains vertices, edges and path of W i.e. remove all edges and vertices that lie outside dispute wheel.

Proof of statement given in section 3.1 can be directly achieved from proof of 3.3.1 and 3.3.2. If there is no dispute wheel, there is no mega-reel which is a special type of wheel. This results in safety under filtering.

4. Safety Enhancement through Regressive Peak Contour

Prior work has only yielded sufficient but not necessary [9]-[11], [14], [16], or necessary but not sufficient [8], [13] conditions for safety on network.

The configuration will not be safe if it permit a mapping from each node to a elected path and a detachment of nodes into two replete sets:

- Steady nodes that in any everlasting impartial activation track ultimately select a path which consists of only steady nodes and unifying with all steady nodes selected paths encompass a uniform routing tree to destination.
- Regressive nodes that are prudish about connecting that steady tree: there exists an everlasting impartial activation track in which they pick a path that initiate with another regressive node as a next hop, favouring it over any paths that go right to the steady tree.

In this section a structure RPC (Regressive Peak Contour) is being proposed. It can be informally defined as peak contour which is formed by node detachment and a path assignment which makes one side of detached steady and other regressive. If a configuration has RPC structure, then steady nodes must achieve steady state under any activation track while regressive nodes have capability to start PRP cycles.

4.1 RPC (Regressive Peak Contour)

4.1.1 Before discussing about safety of PRP, this section describes the formal definition of RPC which requires the following notations:

- Set of regressive nodes $R \subseteq V$.
- Set of steady nodes S=V/R.
- Given a path allocation δ and a regressive set R then set steadyChoices(u,R,δ) can be defined as a set of all paths available to u that go straight to the steady set i.e. all $P \varepsilon P^u$ such that $P=(v,u)P'$ where vεS and $P'=\pi^v$.
- If set steadyChoices(u,R,δ) is replete, the let steadyBest(u,R,δ) be the best path i.e. unique Pε steadyChoices(u,R,δ) for which λ^u (P) is maximum otherwise let stedayBest(u,R,δ) be null.

The pair (δ,R) is **Regressive Peak Contour (RPC)** if the following condition are satisfied:

i. The source is steady i.e. 0εS.
ii. A steady node is allocated its best steady path i.e. for all uεS, π^u=steadyBest(u,R,δ).
iii. There must exist regressive nodes i.e. R≠ϕ.
iv. Path assigned to regressive node is learned from other regressive node only i.e. uεR, $\pi^u=(u,u_{next},\ldots,0)$ with $u_{next}\varepsilon R$. The path assigned to regressive node must have higher rank than u's most preferred steady route i.e. $\lambda^u(\pi^u)>\lambda^u$(steadyBest(u,R,δ)).
v. Every node's allocated path is postfix-uniform with (S,δ) i.e if every postfix of path π^u that initiates with a node sεS is uniform with π^s (if $\pi^u=(u,\ldots,s,P_s,0)$ and sεS, then $\pi^s=(s,P_s,0)$), where P_s is an random subpath.

Two implications can be derived from the above definition of RPC:

4.1.2 In a RPC if u is steady and $\pi^u \neq \phi$, then $\pi^u=(u,P_u^S,0)$ where P_u^S is a subpath which contains only steady nodes.

4.1.3 In a RPC if u is regressive node, then $\pi^u=(u, P_u^R, P_u^S, 0)$ where P_u^R is subpath which contains only regressive nodes and P_u^S is subpath which contains only steady nodes.

The above two implications can br proved by induction on the length of paths allocated by δ. Suppose node selects a path where regressive node comes after steady node. But according to condition V of 4.1.1 there is postfix(s,r,….,0) with sεS and rεR but then π^s violates condition ii.

4.2 Safety of PRP under RPC

This section will show safety of PRP under RPC: "an exponent of PRP cycles if and only if it has a RPC". This statement can be treated in two ways:

4.2.1 If PRP exponent has RPC, then PRP exponent can cycle.

4.2.2 If PRP exponent cycles, then it have RPC.

Both can be proved separately.

Proof of 4.2.1: Given a RPC(R,δ), it serves to find an everlasting impartial activation track in which state of network keeps on changing.

1. Start with an empty a path assigned to each node.
2. Activation track begins by every steady node uεS with $\pi^u \neq \phi$ triggering in breadth first order on steady nodes heap, from destination outward such that each node gets path in π^u which is never modified again.
3. Activate regressive nodes uεR in a cycle form so that each one chooses the path π^u at some point. Select the order of regressive nodes $r_{1\ldots..k}$. For each r_i in order two runs of provocation are done. In round1 stimulate all regressive nodes on regressive prefix of path π^{ri} beginning with node at the contour of steady heap and going toward $r_{i,}$ let them advertise their postfix π^{ri} (pseudo advertisement). When r_i will come then π^{ri} will be accessible, so it or another regressive next hop path will get selected. In round 2 stimulate all the same nodes in the same order and has them transmit pseudo revocation. After this no regressive next hop will be accessible, then r_i will have to modify its path selection. Rerun this track for all the r_is in a circle. Each regressive node will modify its path, which will result in advertisement of pseudo renewals.
4. According to condition ii of 4.1.1 any steady node u cannot have any paths in P^u accessible from its steady neighbors. Thus node u can get announcements of allowed paths from regressive nodes only.

Proof of 4.2.2 Suppose a cycling exponent E and corresponding provocation track constructs a RPC(R,δ). Let S_E be non cyclic node and R_E the cyclic nodes in exponent E. ant non cyclic node uε S_E can permanently selects path (u,v)P which it has acquired from cyclic node $v\varepsilon R_E$. This non cyclic node u can be made to cycle if its provocation track is modified.

Add provocation of the contour (u,v) with pseudo revocation and a second provocation of the contour with a declaration of path P which is a pseudo declaration. Keep on adding nodes to R_E until there are no nodes left that can cycle. δ can be set such that (R_E,δ) is a RPC. For non cyclic nodes $u\varepsilon S_E$, set π^u be the path that is selected permanently. For cyclic nodes $v\varepsilon R_E$, set π^v to be highest ranked path that v will select in cycle.

Now check that (R_E, δ) is a RPC.

1. The source is steady and R_E is replete which satisfies condition i and iii.
2. When above process is repeated , every node s left in S_E will have path π^S which is learned from another node in S_E. according to condition ii, s must select steady path steadtBest(u,R,δ) which should be accessible. This condition is fulfilled because path from s to next hop in S_E are accessible and s selects steadyBest(s,R,δ).
3. Node u will not cycle if uεR_E and the highest ranked path is selected frequently in the cycle which has steady next hop. Then after next hop becomes steady that selected path will become permanently accessible resulting in that u becomes steady, this satisfies condition iv.
4. Suppose rεV is a cycling node, in an exponent PRP. Node r selects a path P at some point during cycle. Node sεV and it does not cycle and suppose path P selected by r contains node s, the node s must permanently select path P[s,0], yielding condition v.

5. Safety Verification of PRP

To verify the safety of PRP this section will show a NON-RPC algorithm. This algorithm constricts possible regressive set, and encompasses an empty regressive set if and only if there is no RPC.

5.1 NON-RPC algorithm

1. Compute S(steady nodes) as S= destination '0' coupled with other nodes that are not connected to destination. Also compute regressive nodes as R=V/S.
2. If R is empty i.e. there are no regressive nodes($u \notin R$) then return safe else goto step 3.
3. If regressive node exist and it satisfies the following conditions then goto step 4 else goto step5.
   3.a) regressive node (u) has a neighbour in steady nodes (S), and
   3.b) node u does not have path (P^u) which is both chosen by u over steadyBest(u,R,δ) and postfix-uniform with (S,δ).
4. Modify S by moving u from R to S and also set path of u as π^u=steadyBest(u,R, δ).
5. Modify S by moving u from R to S and let $\pi^u=\phi$.
6. Return unsafe {(R, δ) is a RPC}.

According to above algorithm a PRP exponent is safe if and only if NON-RPC finish with all nodes in the steady set S. this can be proved in two ways:

5.1.1 PRP is safe if NON-RPC terminates with S=V.

5.1.2 If NON-RPC terminates with regressive nodes then RPC exits hence PRP is unsafe.

Proof of 5.1.1 This can be proved by showing that if NON-RPC adds vertex uεV to steady set S and node u is allocated path π^u, then for any everlasting impartial provocation track in PRP node u must always select path π^u.

This can be shown through induction. The above statement is true for the nodes which are added to steady set at starting as these nodes in PRP model always choose the empty route ф. Also suppose that above declaration also holds for all nodes in set S after step-3 in NON-RPC algorithm. Consider node u which is added to S and assigned path π^u=steadyBest(u,R,δ) in step-3b. by contravention, suppose that there exists some everlasting impartial provocation track in which node u selects a path P which is not equal to π^u($P \neq \pi^u$). Step 3a and 3b in NON-RPC algorithm cease the following condition $\lambda^u(P) > \lambda^u(\pi^u)$ because by induction, all nodes already in S will remain in steady state which will result in withdrawing of announcements made by paths which are not postfix-uniform with (S,δ). The above mentioned condition cannot exist in reverse order $\lambda^u(P) < \lambda^u(\pi^u)$ because π^u will always be accessible to u after next hop reaches steady state after which a less preferred path cannot be selected. Next hop of π^u after entering into steady state will not advertise any other paths then P must have different next hop which cease the following condition $\lambda^u(P) = \lambda^u(\pi^u)$, by the strictness constraint of SPP. Similarly, the declaration holds for any node u allocated to S with an empty π^u in step-5 of NON-RPC algorithm. After S enters steady state, no paths in P^u will be advertised anywhere which will force u to remain without a route after that.

Proof of 5.1.2 When NON-RPC algorithm completes, the π^u for every node uεR is left undefined. This can be completed by allocating π^u to the highest ranked path in P^u which is postfix-uniform with (S,δ). The path allocated to π^u must be replete path and it should be surely higher ranked than steadyBest(u,R,δ). When there is no allowed postfix-uniform path exist then node u would have reached steady state i.e. if $\pi^u \neq \phi$ or if steadyBest(u,R,δ) is empty and there is no allowed postfix-uniform path at all which results in node u entering steady state. This ensures RPC condition iv.

(i),(ii),(v) conditions of RPC at once can be seen from construction if $R \neq \phi$. For steady node S with replete path, examine the next hop s' of path steadyBest(s,R,δ) accepting the latest values of R,S,δ. Assume that s' was added to steady set after s which means that s' would have in R before entering steady set. Because $\pi^{s'}$ was postfix-uniform when it was allocated to s', since it was postfix-uniform prior too. By the end of algorithm that path have become steadyBest(s,R,δ) it should have higher rank path than other paths which were assigned to s as its present steadyBest(s,R,δ) using the operative value of R and S when s entered steady state. This shows that s' does not fulfill condition 3b which hinders s from entering steady stae before s and when s will become steady, steadyBest(s,R,δ)=(s,$\pi^{s'}$) which proves the ii condition of RPC.

6. Conclusion

This paper shows that how cycles can occur in network which were otherwise considered safe in past researches. Further it also established the safety of PRP under well known structures such as dispute wheel and dispute reel. Safety of PRP of was also considered under a new structure mega-reel which proved that PRP is safe under filtering. A new structure RPC is introduced which solved the problem of necessary and sufficient condition for safety. An algorithm based on RPC verified safety in practice. Based on above results it can be shown that efficiency of NON-RPC algorithm is based on route preference and route filtering policies. Further it can be also proved that algorithm runs in polynomial time and its complexity can also be determined from policies it uses.

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Bhavneet kaur is working as an Assistant Professor in Department of Computer Science and Engineering, Guru Nanak Dev University, Amritsar (India). She is pursuing her Ph.D. in Inter-domain Routing protocol at Department of Computer Science and Engineering, Guru Nanak Dev University, Amritsar.

Karanjeet Singh Kahlon is serving as Professor at Computer Science and Engineering Department, Guru Nanak Dev University, India. He has 23 y ears of teaching and research experience. His research areas are parallel/ distributing computing and networks. He has supervised 4 doctoral theses.

Sandeep Sharma received the B.E. in Computer Engineering from Pune University, INDIA in 1994, M.E. degree in Computer Engineering from Thapar Institute of Engg. & Tech. Patiala, INDIA in 2000 and Ph.D. degree from Guru Nanak Dev University Amritsar (Punjab), INDIA in 2011.He is working as Associate professor in department of Computer Science & Engineering and he is also acting as Chief Security Information Officer of the University. His area of interest is Parallel Processing, Multistage Interconnection Network, Fault Tolerance and Cloud Computing.