Patent

Title: Method and process for routing and node addressing in wireless mesh networks

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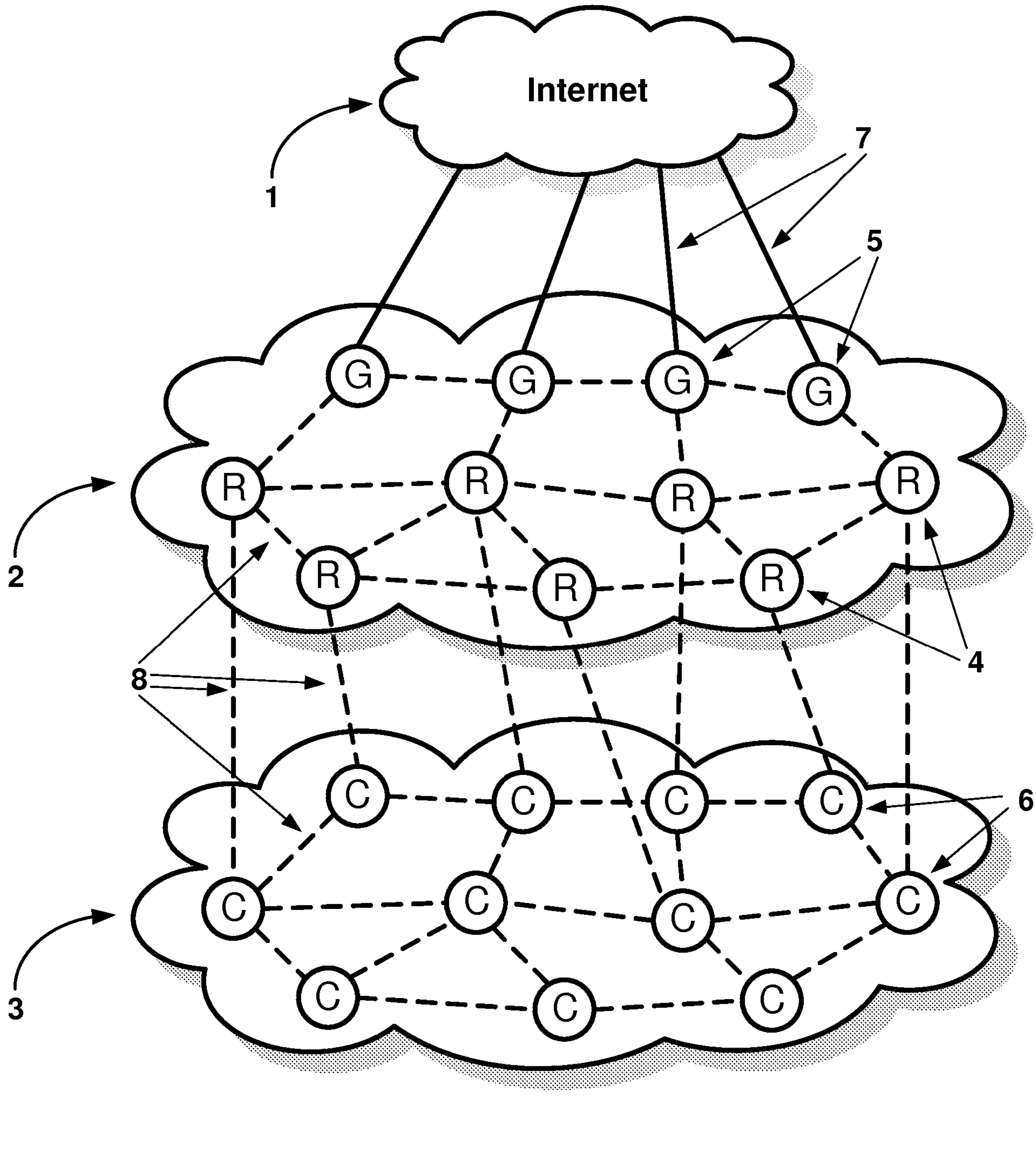


Figure 1

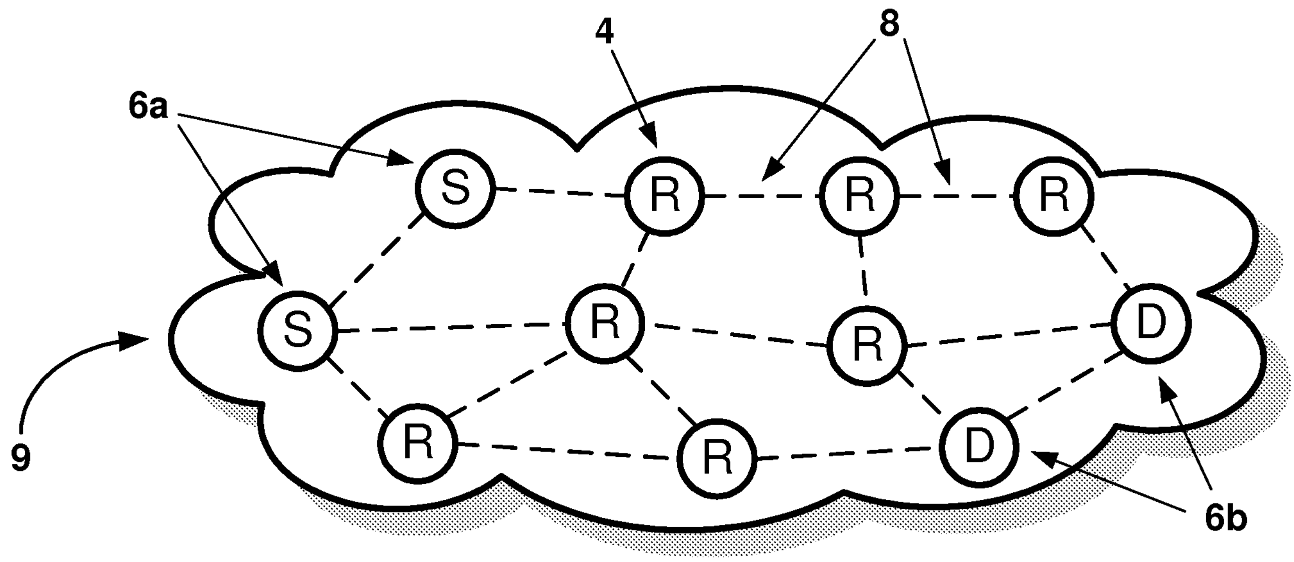


Figure 2

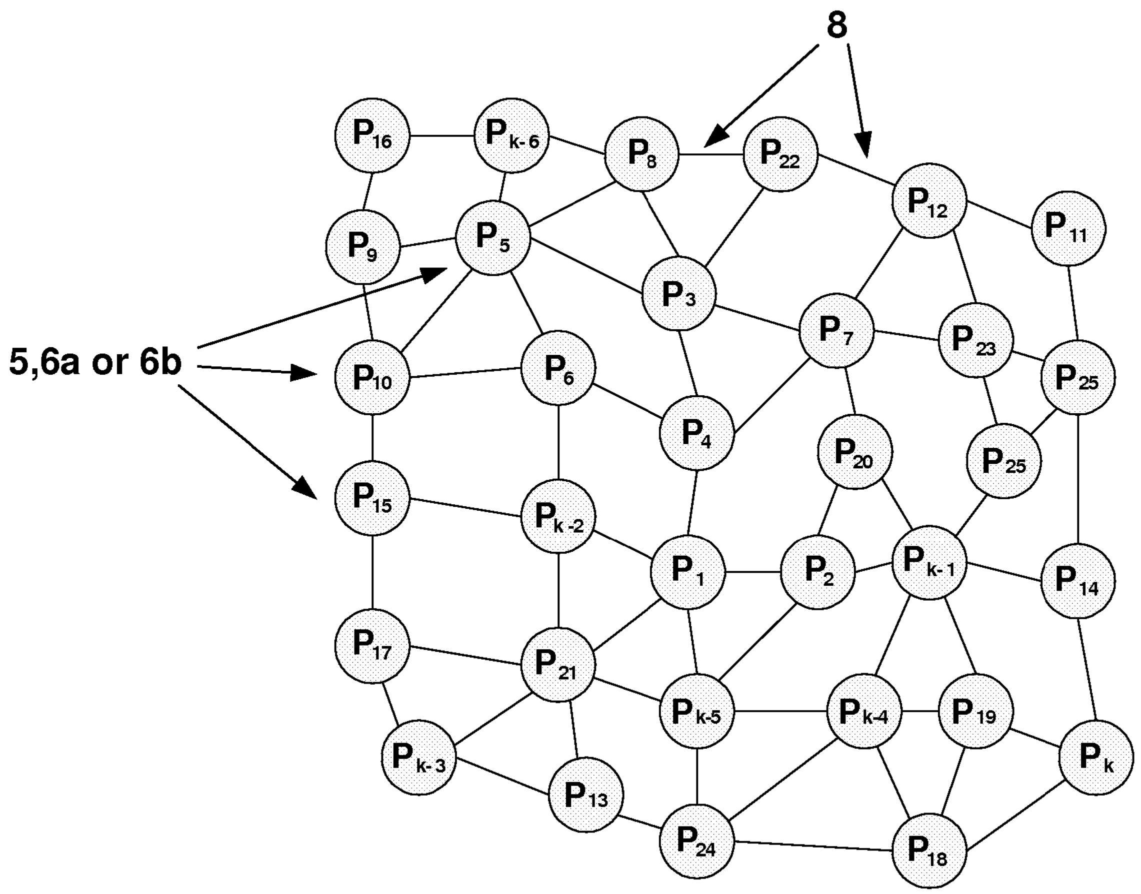


Figure 3

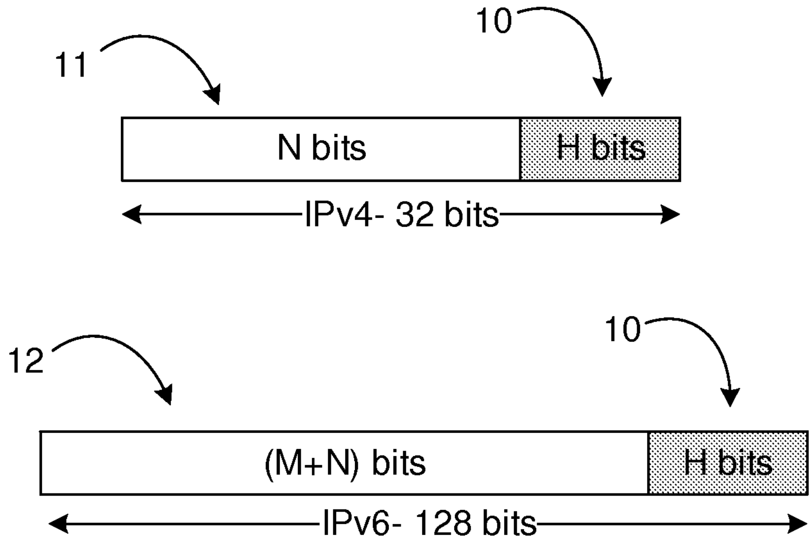


Figure 4a

Bits/ Host	**PN-Prime Number**	**Prime Number (Binary Representation)**	**Prime-IP IP-Address (IPv4-32 bits)**	**Prime-IP IP-Address (IPv6-128 bits)**
8	5	00000101	x.x.x.**5**	xx….**05**
8	239	11101111	x.x.x.**239**	xx…**EF**
16	313	00000001 00111001	x.x.**1.57**	xx… **0139**
16	51449	11001000 11111001	x.x.**200.249**	xx…**C8F9**
24	2051773	00011111 01001110 10111101	x.**31.78.189**	xx…**1F4EBD**
24	12004991	10110111 00101110 01111111	x.**183.46.127**	xx…**B72E7F**
48	9990454997	(0002537A3ED5) $_{hex}$	Not Applicable	XX…**0002537A3ED5**
48	281474076384103	(FFFFCA561B67) $_{hex}$	Not Applicable	XX…**FFFFCA561B67**
64	9007199254740991	(001FFFFFFFFFFFFF)$_{hex}$	Not Applicable	XX…**001FFFFFFFFFFFFF**
64	2305843009213693951	(1FFFFFFFFFFFFFFF)$_{hex}$	Not Applicable	XX…**1FFFFFFFFFFFFFFF**

Figure 4b

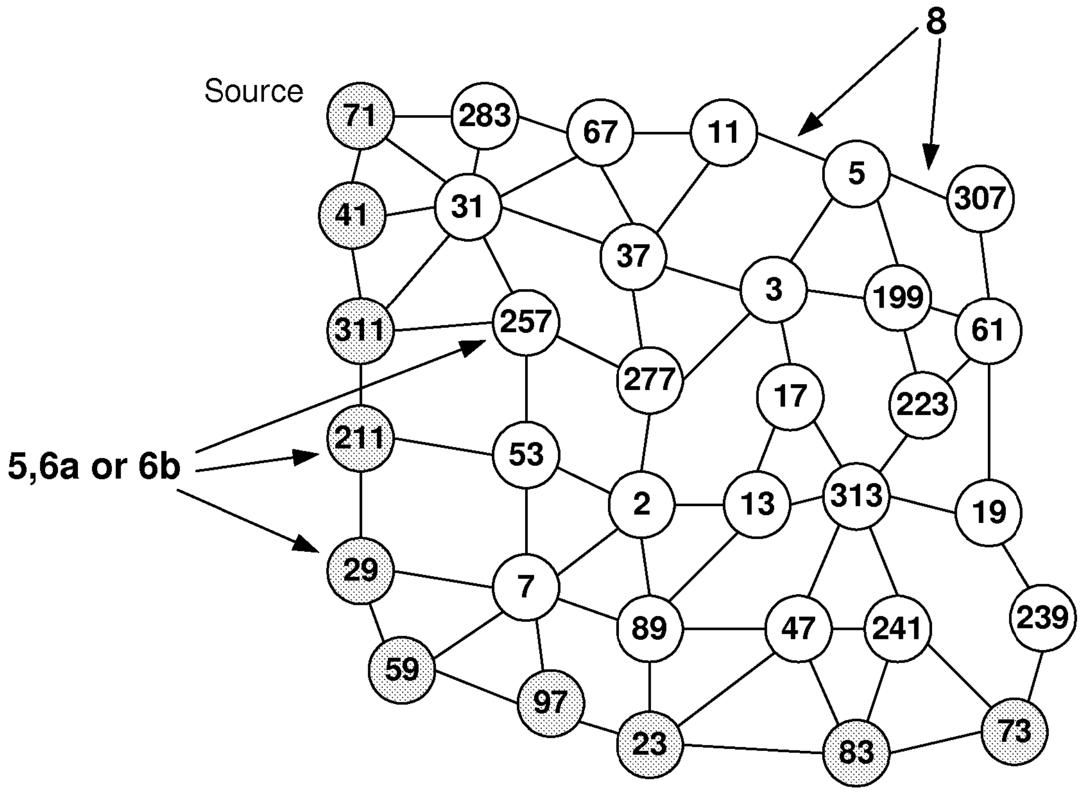


Figure 5a

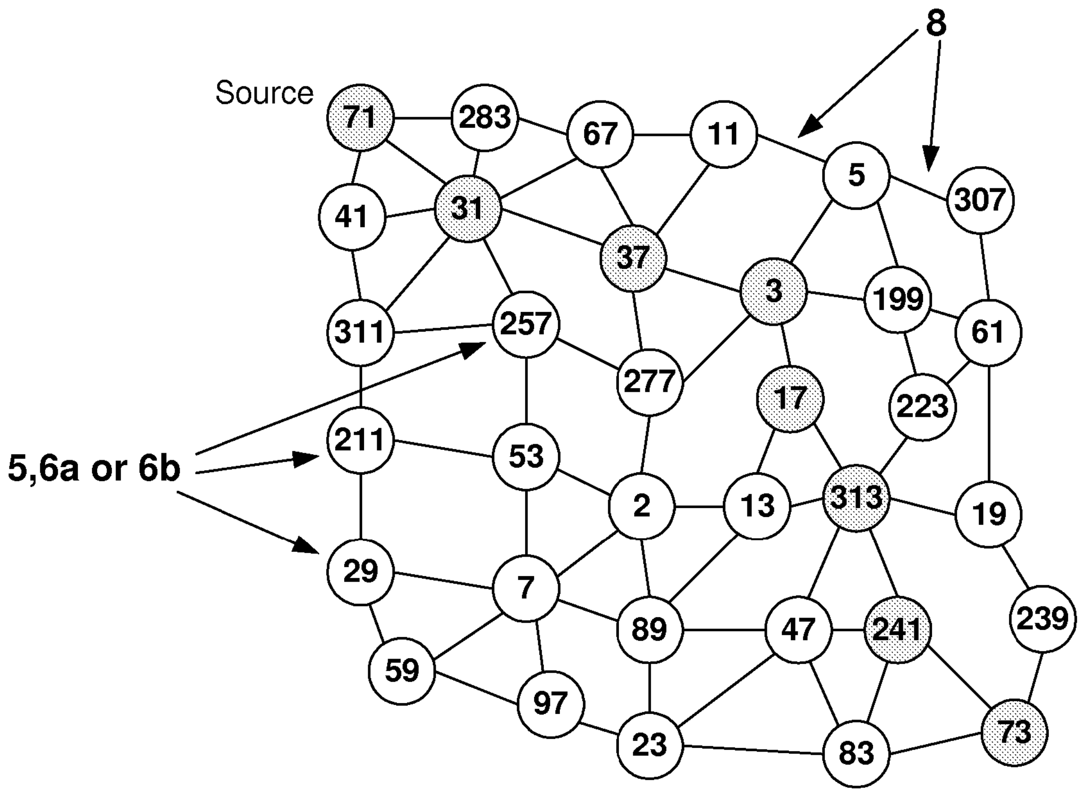


Figure 5b

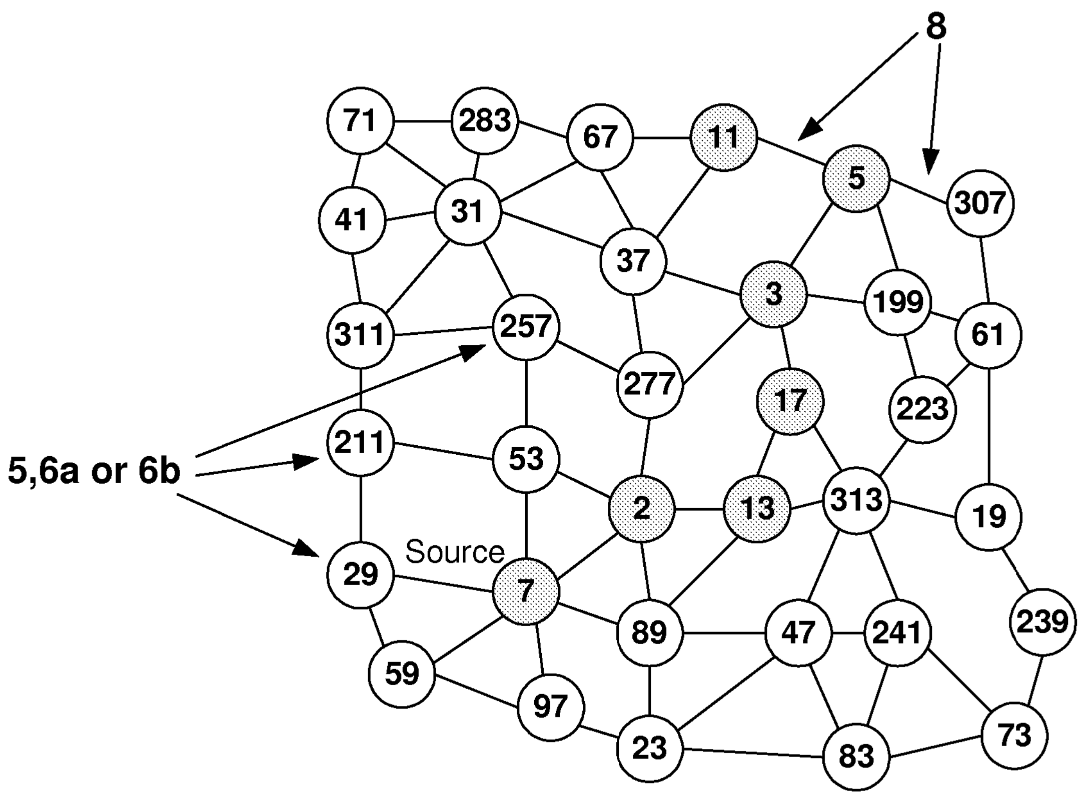


Figure 5c

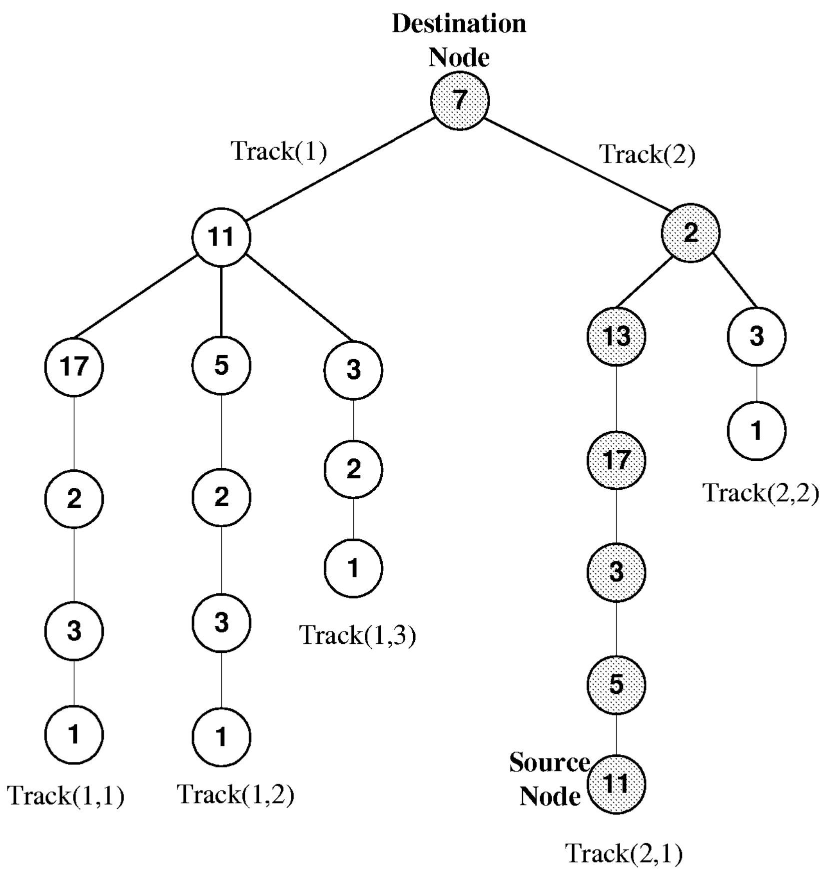


Figure 5d

PPN_1 and PPN_2 value calculations from highlighted route in figure 5a		
PN	**PPN_1**	**PPN_2**
73	73-Destination	72
83	6059	5975
23	139357	137424
97	13517629	13330127
59	797540111	786477492
29	23128663219	22807847267
211	4880147939209	4812455773336
311	1517726009093999	1496673745507495
41	62226766372853959	61363623565807294
71	Source Node	Source Node

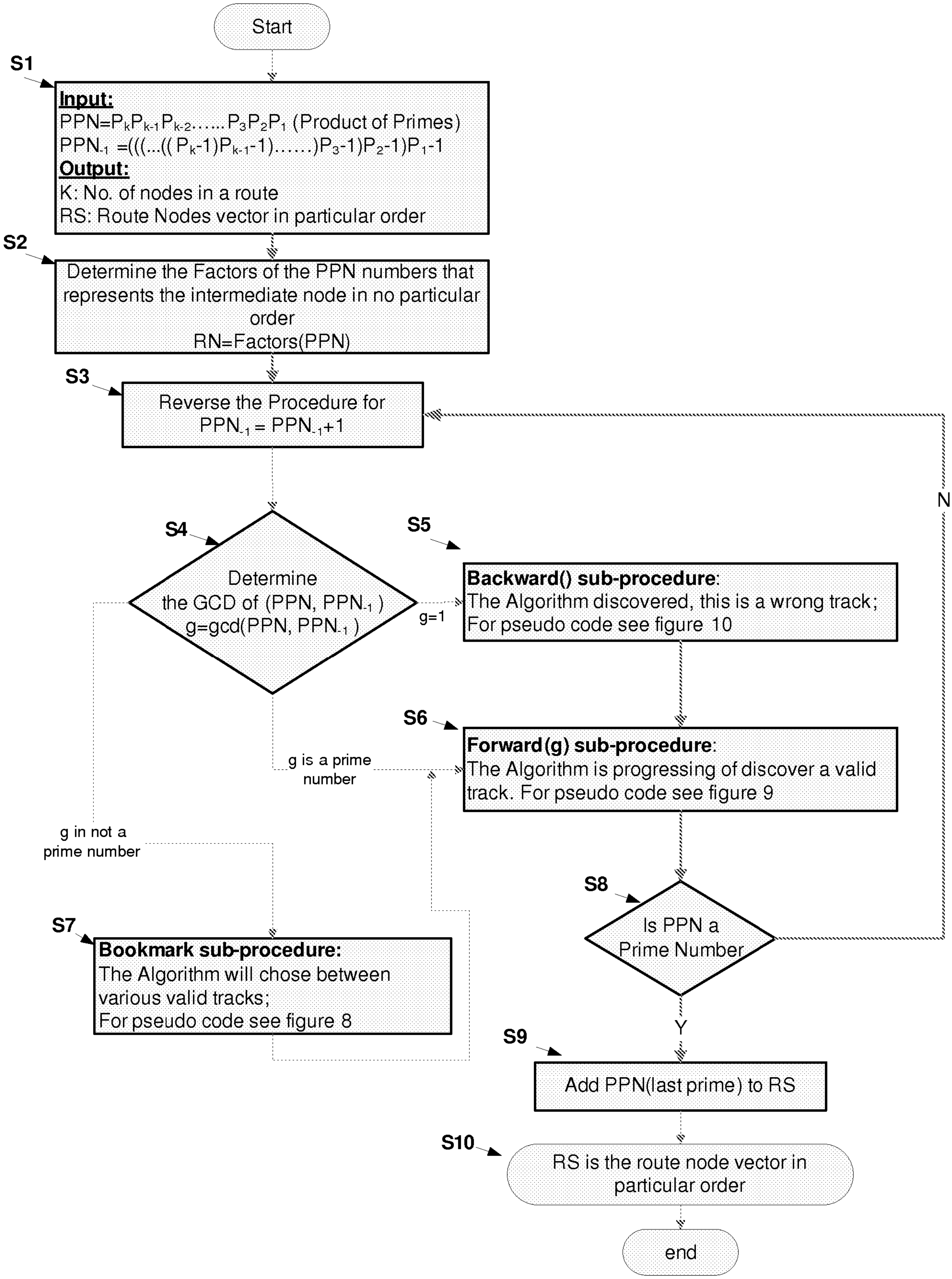
Figure 6a

PPN_1 and PPN_2 value calculations from highlighted route in figure 5b		
PN	**PPN_1**	**PPN_2**
73	73-Destination	72
241	17593	17351
313	5506609	5430862
17	93612353	92324653
3	280837059	276973958
37	10390971183	10248036445
31	322120106673	317689129794
71	Source Node	Source Node

Figure 6b

PPN_1 and PPN_2 value calculations from highlighted route in figure 5c		
PN	**PPN_1**	**PPN_2**
11	11-Destination	10
5	55	49
3	165	146
17	2805	2481
13	36465	32252
2	72930	64503
7	Source Node	Source Node

Figure 6c



Start
S1
Input:
PPN=$P_kP_{k-1}P_{k-2}$…...$P_3P_2P_1$ (Product of Primes)
PPN_{-1} =(((...((P_k-1)P_{k-1}-1)……)P_3-1)P_2-1)P_1-1
Output:
K: No. of nodes in a route
RS: Route Nodes vector in particular order
S2
Determine the Factors of the PPN numbers that represents the intermediate node in no particular order
RN=Factors(PPN)
S3
Reverse the Procedure for
PPN_{-1} = PPN_{-1}+1
S4
Determine
the GCD of (PPN, PPN_{-1})
g=gcd(PPN, PPN_{-1})
S5
g=1
Backward() sub-procedure:
The Algorithm discovered, this is a wrong track;
For pseudo code see figure 10
N
S6
g is a prime number
Forward(g) sub-procedure:
The Algorithm is progressing of discover a valid track. For pseudo code see figure 9
g in not a prime number
S8
Is PPN a Prime Number
S7
Bookmark sub-procedure:
The Algorithm will chose between various valid tracks;
For pseudo code see figure 8
Y
S9
Add PPN(last prime) to RS
S10
RS is the route node vector in particular order
end

Figure 7

```
Bookmark sub-procedure:
{
// Whilst g is multiple of Prime Numbers
// gx: is factors of the g
// Bmark: Bookmark array which will be used for the
// backward/forward functions in the Backtrack procedure.
// The Bookmark Structure is:
// Bmark(INX,1) = 0, only one prime
                 > 0,  Multiple of Primes
//Bmark(INX,2) = Number of Factors of the GCD at this point
//Bmark(INX,3) = PPN at this point
//Bmark(INX,4) = PPN-1 at this point
//Bmark(INX,5) = GCD at this point
//Bmark(INX,6) = LB, Previous Benchmark

        gx=sort(factor(g),'descend');
        Bmark(INX,1)=Bmark(INX,1)+1;
        Bmark(INX,2)=length(gx);
        Bmark(INX,3)=PPN;
        Bmark(INX,4)=PPN1;
        Bmark(INX,5)=g;
        Bmark(INX,6)=LB;
        LB=INX;
        Forward(gx(Bmark(INX,1)));
}
```

Figure 8

```
Forward(g) sub-procedure
{
        PPN=PPN/g;
        PPN1=PPN1/g;
        Remove g from RN vector;
        Add g to the end of RS vector;
        INX=INX+1;
}
```

Figure 9

```
Backward() sub-procedure
{
//Bsteps : How many backward steps
//LB: Last Bookmark
    Bsteps=INX-LB-1;
    INX=LB;
    Bmark(INX,1)=Bmark(INX,1)+1;
    PPN=Bmark(INX,3);
    PPN1=Bmark(INX,4);
    GD=Bmark(INX,5);
    bgx=factor(GD);
// Add  the wrong track prime numbers to the RN vector again
      RN=[RN RS(end-Bsteps:end)];
// Remove  the wrong track prime numbers from the end of the RS vector
      RS(end-Bsteps:end)=[];
    if Bmark(INX,1)<=Bmark(INX,2)
        PR=bgx(Bmark(INX,1));
    else
        Bmark(INX,1)=0;
        LB=Bmark(INX,6);
        PR=Backward();
    end
Return PR
}
```

Figure 10

Method and Process for Routing and Node Addressing in Wireless Mesh Networks

Description:

The invention proposed in this patent is named Prime-IP. Prime-IP is a novel routing algorithm for Wireless Mesh Networks (WMN).

Prime-IP achieves higher Quality of Service than standard WMN implementations because it will always choose the optimum route path between the source node and the destination node. i.e. Prime-IP achieves more reliable routes, less traffic processing overhead, higher security level, increased data throughput, and reduced error rate.

Furthermore, Prime-IP produces unique routing path were each individual node are identified, and were the route can be classified by each of these individual nodes. i.e. with Prime-IP, each node will have knowledge of not only the neighbouring nodes, but also nodes that are beyond their neighbours nodes. Consequently, Prime-IP builds, at each node level, a dynamic knowledge database (or map) of all other nodes in the WMN.

Prime-IP achieves this by:

(a) Assigning a unique prime number in the host-portion of the IP-Address of each individual node.

(b) Packs two extra number fields in the Route REply Packet (RREP) named PPN_1 and PPN_2. The value of these two fields will be calculated dynamically during the route reply discovery stage.

(c) The values of PPN_1 and PPN_2 are calculated from the prime numbers allocated to the nodes in the WMN, starting with the destination node (the initial value of PPN_1= "destination node prime number", while PPN_2= "destination node prime number" - 1). Thereafter, as RREP get forwarded by the destination node to the neighbouring nodes, PPN_1 and PPN_2 values change to (newPPN_1=

previousPPN_1 x CurrentNodePrimeNumber) and (newPPN_2= (previousPPN_2 x CurrentNodePrimeNumber) - 1). This process continues for the next intermediate nodes until the routes reach the source node.

(d) Based on the values of received PPN_1 and PPN_2 from the various possible paths between the destination and the source nodes, the source node then uses a backtrack procedure to construct the intermediate nodes vector in a particular order for each of the received RREPs. This then is used to select the optimum available route out of all the possible path options.

Typical WMN are classified to three categories as Infrastructure WMNs, Client WMNs and Hybrid WMNs. The intermediate nodes in all these categories, using current conventional routing algorithms, do not accumulate knowledge beyond their nearest neighbouring nodes. Prime-IP can be applied to all of these categories of WMNs and therefore all nodes shall have knowledge beyond their neighbouring nodes.

Examples:

The following 3 examples are designed to illustrate the working (method and process) of Prime-IP in (a) assigning the Prime Number, (b) Calculating PPN_1 and PPN_2, and (c) construct the optimum route using the backtrack procedure. In these examples the following Diagrams and Tables are used:

List of Figures:

Figure 1 shows a diagram of a general WMN topology,

Figure 2 shows a diagram of a general Client WMN topology (sometimes called Mobile Ad-Hoc Networks (MANET)),

Figure 3 shows a diagram of a random WMN topology with a prime number address (P_1, P_2, …, P_i, …, P_k) assigned to every node.

Figure 4a shows the host portions (H bits) and the network portions in the IPv4 and IPv6 address format,
Figure 4b shows how prime numbers are embedded in the IP addresses (Ipv4 and Ipv6) with different host portion sizes (H bits),

Figure 5a, 5b and 5c shows the diagram from Figure 3, but with actual Prime number assigned to all node address ($P_1 \ldots P_k$), and highlighting 3 route examples,
Figure 5d shows a tree diagram of how the “backtrack procedure” is applied to determine the track which represents the intermediate nodes vector in that particular order,

Figures 6a, 6b and 6c show examples of constructing and deconstructing of the “Product of the Prime Numbers” (PPN_1 and PPN_2) for the routes highlighted in figures 5a, 5b and 5c respectively,

Figure 7 shows a flow chart of the overall Backtrack procedure,
Figure 8 shows a pseudo-code description of the Bookmark sub-procedure,

Figure 9 shows a pseudo-code description of the Forward sub-procedure, and

Figure 10 shows a pseudo-code description of the Backward sub-procedure.

Figures Explanation:

In figure 1, a general WMN has been construct by using three different domains; Internet 1, Mesh Route Domain (MRD) 2 and Mesh Client Domain (MCD) 3. The MRD, contains “mesh routers” nodes 4 which is equipped with high processing and memory capabilities. Some of the “mesh routers” are also called gateways 5, which are special wireless routers with high-bandwidth wired connection to the Internet. In the MCD, the “mesh clients” 6 are mobile nodes. The links between the Internet 1 and the MRD through the gateways 5 are wired connections 7. The links between the MRD and MCD are wireless connections 8.

In figure 2, a general Client Wireless Mesh Network (also called Mobile Ad-Hoc Network (MANET)) 9 has been illustrated; it is a number of mobile nodes in random topology without base-station or access point. The mobile nodes can be classified to senders 6a, destinations 6b and routers 4 which are dynamically changed upon their instant functionality.

In Figure 3, assuming there is a WMN network with random topology, each circle represents an individual wireless node 5, 6a and 6b. The lines between these circles are the bi-directional links between two nodes 8. Finally, all nodes have been assigned a unique prime number as described below.

In Figure 4a, both IP address versions (IPv4 and IPv6) are illustrated with their host portion 10 and network portions 11, 12 respectively.

Prime-IP Description

The Prime-IP is designed for a dynamic network topology (WMN) where the topology and membership (nodes' association/re-association) may change at any time. It is based on the "*Fundamental theory of Arithmetic*" that states:

(a) Every positive integer (except the number 1) can be represented in one way only apart from rearrangement as a product of one or more primes.

(b) Every natural number is either prime or can be uniquely factored as a product of primes in a unique way.

To devise a general formula for calculating PPN_1 and PPN_2 in Prime-IP, it is assumed that any route is represented by a number of nodes starting in sequence from source node being P_1 till the destination node P_d with any variable number of nodes in between $P_1, P_2, \ldots, P_{d-1}, P_d$.

NB, the use of the term "route" signify a definitive physical intermediate nodes between the source and destination nodes, while term "path" is used to signify any possible route via any combination of physical intermediate nodes.

Also, assume $P_i \in RN$,

Where:

P_i is an arbitrary prime number,

RN is a set of prime numbers

where $RN = \{P_1, P_2, P_3, \ldots, P_i, \ldots P_{k-2}, P_{k-1}, P_k\}$, in ascending order,

RS is an arbitrary set of prime,

where $RS \subseteq RN$,

P_k = largest prime number in RN,

$1 \le i \le k$, i is an integer number,

k = total of prime numbers in RN set,

$RS = \{P_j\}$, where $1 \le j \le d$, $d \le k$, and

d = total of prime numbers in RS set (intermediate nodes)

Then

PPN_1= Product ($P_d\, P_{d-1}\, P_{d-2} \ldots P_3\, P_2\, P_1$), and

Factors (PPN_1) $\Leftrightarrow$ { $P_d P_{d-1} P_{d-2} \ldots P_3 P_2 P_1$ }

And

$PPN_2 = (((\ldots ((P_d -1)\, P_{d-1} -1)\ldots)\, P_3 -1)\, P_2 -1)\, P_1 -1$,

Or, put in a series format,

$PPN_2 = (P_d P_{d-1} P_{d-2} \ldots P_3 P_2 P_1) - (P_{d-1} P_{d-2} \ldots P_3 P_2 P_1) - \ldots - (P_3 P_2 P_1) - (P_2 P_1) - (P_1) - 1$

i.e. in general, and substituting for the value of PPN_1 in PPN_2,

$$PPN_2 = PPN_1 - \sum_{i=d-1}^{1} [\prod_{j=1}^{i} (P_j)] - 1$$

This shows that PPN_1 will always be greater than PPN_2

In conclusion, therefore, there is one and only one:

1. Factors-set (RS) for each PPN_1.

2. PPN_1 is a product of the RS elements set.

However, these operations do not produce the list of prime factors in any particular order. Prime-IP produces the list of prime factors in a particular order, which is the same as the sequence of the factors order produced by the constructing process.

Figure 3 shows that all nodes have been assigned a unique prime number as an address Pi {where $Pi= P_1 \ldots P_k$}. Therefore, in order to have a route from a source node to a destination node through intermediate routing nodes, the source node issues "route request packet" (RREQ). A flooding process is then ensued in various paths until the destination node is reached. As soon as the destination node gets this request, a "route reply packet" (RREP) shall be returned to the source node via various path options. Finally, the source node establishes the optimum route from these available route options. i.e. in Figure 3, for example, a source node can be P_{16} which issues a RREQ to reach P_1 as a destination node. There are various routes that could be selected to do this, such as

$RS_1 = \{P_1, P_4, P_6, P_5, P_9\}$,

$RS_2 = \{P_1, P_4, P_3, P_8, P_{k-6}\}$,

$RS_3 = \{P_1, P_{k-2}, P_{15}, P_{10}, P_9\}$,

Etc.

i.e. the P_1 responds by an RREP and puts its prime number address in the reserved fields PPN_1 and PPN_2. So, all the intermediate nodes between P_1 and P_{16} shall replace the value of PPN_1 and PPN_2 by (a) multiplying their prime number address with the existing value of the PPN_1, and (b) multiplying their prime number address with the existing value of the PPN_2 then subtracting 1 from PPN_2. Finally, P_{16} will receive various values of PPN_1 and PPN_2 dependent on the nodes that RREP path passes through. i.e. the value of PPN_1 & PNN_2 in the RREP for RS_1 shall be

$PNN_1 = P_1 \text{ x } P_4 \text{ x } P_6 \text{ x } P_5 \text{ x } P_9$

$PPN_2 = (((((P_1\text{-}1)\text{x}P_4\text{-}1)\text{x}P_6\text{-}1)\text{x}P_5\text{-}1)\text{x}P_9\text{-}1)$, or

$= (P_1 \text{ x } P_4 \text{ x } P_6 \text{ x } P_5 \text{ x } P_9)\text{- } (P_4 \text{ x } P_6 \text{ x } P_5 \text{ x } P_9)\text{- } (P_6 \text{ x } P_5 \text{ x } P_9)\text{- } (P_5 \text{ x } P_9)\text{-}$
$(P_9)\text{-}1$

As this example demonstrates, the use of prime numbers as an address is unique, and shall provide unique identification of all the nodes, in all the possible paths in any routing discovery process (include both node-IP's and sequence).

NB. The possible prime number assignment is however limited to, for example, 54 prime numbers in any 8-bit addressable field (where all possible numbers are 255). This should not limit Prime-IP because the host portion of IP address filed can be extended to 16, 24 and up to 64 bits in IPv6.

Furthermore, the source node will accumulate information about all possible intermediate nodes to the destination node (generated by Prime-IP backtrack procedure, using only two variables PPN_1 and PPN_2). Therefore, Prime-IP potentially can generate a dynamic map of the entire WMN.

Prime- IP and IP Addresses:

Figure 4a shows both IP address versions (IPv4 and IPv6) with their host portion and network portions. The length of the IPv4 is 32 bits (The host portion of the IP address is 2-24 bits, while the reminder bits are used for the network portion). The length of the IPv6 address is 128 bits allowing for the host portion to be up to 64 bits.

Figure 4b illustrates an example of arbitrary prime numbers selection. These are chosen for different host portion lengths for both IPv4 and IPv6. i.e.

- For 8 bits host portion, there are only 54 prime numbers that are possible (total numbers= 256 or $2^{\wedge 8}$). For instant, 5 and 239 are prime numbers are converted to 8 bits binary as (00000101) and (11101111) respectively. i.e. to generate the Prime-IP addresses (x.x.x.5 and x.x.x.239) for IPv4 and (xx...5 and xx…EF) for IPv6. Note that “x” in the above IP addresses represents the network portion number.
- For 16 bits host portion, there are about 6000 possible prime numbers, out of total numbers of 65,536 ($2^{\wedge 16}$). For instant, 313 and 51,449 are prime numbers are converted to 16 bits binary as (00000001-00111001) and (11001000-11111001) respectively. This is to generate the Prime’s IP

addresses (x.x.1.57 and x.x.200.249) for IPv4 and (xx...0139 and xx…C8F9) for IPv6.

- For host portion using 24 bits, there are around one million prime numbers that can be used ($2^{\wedge 24}$ =16,777,216). For instant, 2,051,773 and 12,004,991 are prime numbers and are converted to 24 bits binary as (00011111-01001110-10111101) and (10110111-00101110-01111111) respectively. Thus generating the Prime's IP addresses (x.31.78.189 and x.183.46.127) for IPv4 and (xx...1F4EBD and xx…B72E7F) for IPv6.
- In the host portion of 48 bits, there are around eight trillion prime numbers out of ($2^{\wedge 48}$) numbers. For instant, 9,990,454,997 and 281,474,076,384,103 are prime numbers which are converted to 48 bits in hexadecimal as $(0002537A3ED5)_{hex}$ and $(FFFFCA561B67)_{hex}$, respectively, to generate the Prime's IP addresses (xx... 0002537A3ED5 and xx… FFFFCA561B67) for IPv6. There is no entry for IPv4 in table 6b because it is 32 bits length, and so it is not applicable in the case.
- For 64 bits host portion, there are around $4*10^{17}$ prime numbers out of ($2^{\wedge 64}$). For instant, 9,007,199,254,740,991 and 2,305,843,009,213,693,951 are prime numbers which have being converted to 64 bits in hexadecimal as $(001FFFFFFFFFFFFF)_{hex}$ and $(1FFFFFFFFFFFFFFF)_{hex}$ respectively to generate the Prime- IP addresses (xx...001FFFFFFFFFFFFF and xx…1FFFFFFFFFFFFFFF) for IPv6.

Prime- IP Backtrack Procedure

For every available route from the source node to the destination node, Prime-IP backtrack procedure generates the vector containing the intermediate node addresses in a particular order. PPN_1 and PPN_2 numbers are used as input to the backtrack procedure. The “source node” gets a route replay packets containing the PPN_1 and PPN_2 numbers. As shown in figure 5a and figure 5b, two different routes are highlighted between the source node-71 and the destination node-73. Figure 5c shows a highlighted route between source node-7 and the destination node-11.

Figures 6a, 6b and 6c demonstrate the values of PPN_1 and PPN_2 in the highlighted routes that have been illustrated in Figures 5a, 5b and 5c respectively. In each of these examples, the source node gets a set of PPN_1 and PPN_2 numbers which is classified as following:

Route shown in figure 5a and 6a:

PPN_1= 622,26,766,372,853,959

PPN_2= 61,363,623,565,807,294

Route shown in figure 5b and 6b:

PPN_1= 322,120,106,673

PPN_2= 317,689,113,736

Route shown in figure 5c and 6c:

PPN_1= 72,930

PPN_2= 64,503

After the route reply packet has been received by the source node, the backtrack procedure will start to generate the vector (RS). Figure7 shows a flowchart of this procedure, which includes the iterations performed to consider all possibilities in forming the route vectors.

Main Backtrack Procedure Flowchart using Figure 5a and 6a examples

To illustrate the backtrack procedure, the PPN_1 and PPN_2 numbers for the highlighted route in Figure 5a will be used to explain the flowchart of Figure 7:

1. In S_1, five variables have been defined:

   Input Variables:

   PPN_1= 62,226,766,372,853,959

   PPN_2= 61,363,623,565,807,294

   Output Variables:

   K: Number of intermediate nodes in a route

   RN: Intermediate Route Nodes vector in no particular order

   RS: Intermediate Route Nodes vector in a particular order

   Local Variables:

   INX: Index

2. In S_2, determine the RN vectors by factorising the PPN1 number that represents the intermediate nodes in a no-particular order.

   RN= Factors (PPN_1) = [23,29,41,59,73,83,97,211,311]

3. In S_3, add one to the PPN_2:

   PPN_2= PPN_2 +1= 61,363,623,565,807,295

4. In S_4, determine the GCD of PPN_1 and PPN_2:

   g = GCD (PPN_1, PPN_2), GCD is Greater Common Division

   = GCD (62226766372853959, 61363623565807295)= [41]

5. Also in S_4,
   - if g= 1: then the procedure is tracking the wrong track; therefore, the backward sub-procedure is invoked (described in Figure 10) to backtrack the procedure to the last benchmark in S_5.
   - If g= not a prime number (in this example, g= 41): then the procedure will chose between various valid tracks.
   - if g= a prime number: then g= 41 and we progress to discover a valid track.

6. In S_6, the forward sub-procedure is invoked as described in Figure 9. This moves the process forward by calculating the values to discover node 41:

   PPN_1= PPN_1/g= 62,226,766,372,853,959/41= 1,517,726,009,093,999

   PPN_2= PPN_2 /g = 61,363,623,565,807,295/41= 1,496,673,745,507,495

   Remove the first prime number [41] from RN and add it to RS

   RN= [23,29,59,73,83,97,211,311]

   RS= [41], INX= INX+1= 1

7. In S_8, if PPN_1 is not a prime number, then go to S_3.

8. Repeat (3-7) above as many times as necessary in order to obtain the final RS that represents all the intermediate route nodes vector in a particular order. The following is to discover node 311:

   PPN_2= PPN_2 +1= 1,496,673,745,507,495+1= 1,496,673,745,507,496

   g= GCS (PPN_1, PPN_2)

   = GCD(1517726009093999, 1496673745507496)= [311]

   PPN_1= PPN_1/g= 1,517,726,009,093,999/311= 4,880,147,939,209

   PPN_2= PPN_2 /g = 1,496,673,745,507,496/311= 4,812,455,773,336

   RN= [23,29,59,73,83,97,211]

   Remove the prime number [311] from RN and add it to RS. i.e.

   RS= [41,311], INX= INX+1= 2

Again, for node 211:

PPN_2= PPN_2 +1= 4,812,455,773,336+1= 4,812,455,773,337

g= GCS (PPN_1,PPN_2)= GCD(4880147939209, 4812455773337)= [211]

PPN1 = PPN_1/g= 4,880,147,939,209/211= 23,128,663,219

PPN2 = PPN_2 /g = 4,812,455,773,337/211= 22,807,847,267

RN= [23,29,59,73,83,97],

Remove the prime number [211] from RN and add it to RS

RS= [41,311,211], INX= INX+1= 3

Again for node 29:

PPN_2= PPN_2 +1= 22,807,847,267+1= 22,807,847,268

g= GCS (PPN_1, PPN_2) = GCD (23128663219, 22807847268)= [29]

PPN_1 = PPN_1/g= 23,128,663,219/29= 797,540,111

PPN_2 = PPN_2 /g = 22,807,847,268/29= 786,477,492

RN= [23, 59, 73, 83, 97],

Remove the prime number [29] from RN and add it to RS

RS= [41, 311, 211, 29], INX= INX+1= 4

Again for node 59:

PPN_2= PPN_2 +1= 786,477,492+1= 786,477,493

g= GCS (PPN_1, PPN_2)= GCD(797540111, 786477493)= [59]

PPN_1 = PPN_1/g= 797,540,111/59= 13,517,629

PPN_2 = PPN_2 /g = 786,477,493/59= 13,330,127

RN= [23, 73, 83, 97],

Remove the prime number [59] from RN and add it to RS

RS= [41, 311, 211, 29, 59], INX= INX+1= 5

Again node 97:

PPN_2= PPN_2 +1= 13,330,127+1= 13,330,128

g= GCS (PPN_1, PPN_2) = GCD(13517629, 13330128)= [97]

PPN_1 = PPN_1/g= 13,517,629/97= 139,357

PPN_2 = PPN_2 /g = 13,330,128/97= 137,424

RN= [23, 73, 83],

Remove the prime number [97] from RN and add it to RS

RS= [41, 311, 211, 29, 59, 97], INX= INX+1= 6

Again, this time for node 23:

PPN_2= PPN_2 +1= 137,424+1= 137,425

g= GCS (PPN_1, PPN_2)= GCD(139357, 137425)= [23]

PPN_1 = PPN_1/g= 139,357/23= 6,059

PPN_2 = PPN_2 /g = 137,425/23= 5,975

RN= [73, 83],

Remove the prime number [23] from RN and add it to RS

RS= [41, 311, 211, 29, 59, 97, 23], INX= INX+1= 7

Again, finally for node 83:

PPN_2= PPN_2 +1= 5,975+1= 5,976

g= GCS (PPN_1, PPN_2)= GCD(6059, 5976)= [83]

PPN_1 = PPN_1/g= 6,059/83= 73

PPN_2 = PPN_2 /g = 5,976/83= 72

RN= [73]

Remove the first prime number [83] from RN and add it to RS

RS= [41, 311, 211, 29, 59, 97, 23, 83], INX= INX+1= 8

9. In S_8, if PPN_1 is a prime number then this is also the destination node, (in this example, PPN_1= 73), and so go to S_9

10. In S_9, add (73) to RS= [41, 311, 211, 29, 59, 97, 23, 83, 73]

11. In S_{10}, Finally, RS represents the highlighted route in figure 5a and 6a in this particular order.

Another Backtrack Procedure Example, but also invoking the backward-sub-procedure as shown in figure 5c and 6c example:

To illustrate the backtrack procedure further, the PPN_1 and PPN_2 numbers for the highlighted route in Figures 5c/6c will be used to explain the flowchart of Figure 7, but when the backward-sub-procedure is also invoked, as follows:

1. S_1, 5 variables have been defined:

   Input Variables:

   PPN_1 = 72,930

   PPN_2 = 64,503

   Output Variables:

   K: Number of intermediate nodes in a route

   RN: Intermediate Route Nodes vector in no-particular order

   RS: Intermediate Route Nodes vector in particular order

   Local Variables:

   INX: Index

2. S_2, determines the RN vectors by factorising the PPN_1 number that represents the intermediate nodes in no-particular order.

   RN= Factors (PPN_1) = [2, 3,5, 11, 13, 17]

3. S_3, add one to PPN_2:

   PPN_2= PPN_2 +1= 64,504

4. S_4, determine the GCD of PPN_1 and PPN_2:

   g= GCS (PPN_1, PPN_2)= GCD(72930, 64504)= [22]

   - if g= 1: then the procedure is tracking the wrong track; therefore, the backward sub-procedure is invoked (described in Figure 10) to backtrack the procedure to the last benchmark in S_5.
   - if g is a prime number: No
   - If g= not a prime number (in this example, g= 22): then the procedure will choose between various valid tracks, then, S_7.

5. S_7 (more details in Figure 8), Bookmark Sub-procedure,

   gx: Factors of g in descending order (g is not prime number).

   Bmark: Bookmark array used for the forward and backward sub-procedures as described figure 9 and figure 10.

   The Bookmark Structure is:

   Bmark(INX,1) = Branch :0 only one prime, :i^{th} Multiple of (n-1) Prime number

   Bmark(INX,2) = Number of Factors of the GCD at this point (number of branches)

   Bmark(INX,3) = PPN_1 at this point

   Bmark(INX,4) = PPN_2 at this point

   Bmark(INX,5) = GCD at this point

   Bmark(INX,6) = LB is the Previous Bookmark

Figure 5d illustrates the behaviour of the backtrack procedure (showing “depth-first search” algorithm when in a tree structure). Prime-IP assigns a bookmark (Bmark array) for every branch, when more than one track is possible. For instant, at this point, gx= factors (22)= [11,2] in descending order. The procedure shall choose between two tracks, either [11] or [2]. While gx vector has been sorted in descending order, selecting the prime number will also be in descending order. As shown in figure 5d, node [11] is selected as the next node is track(1). If the procedure discovers that track(1) is the wrong track selection, then node [2] shall be selected as a next node in track(2).

Bmark(1,1) = 1, track(1)

Bmark(1,2) = 2 , represents the number of various valid tracks at this bookmark point

Bmark(1,3) = 72,930 , PPN_1 at this point

Bmark(1,4) = 64,504 , PPN_2 at this point

Bmark(1,5) = 22 , g at this point

Bmark(1,6) = 1 , LB represents a Previous Bookmark

Forward(gx(Bmark(1,1))) → Forward(11) ,move the procedure forward.

6. S_6, the forward sub-procedure is invoked as described in Figure 9. This moves the process forward by calculating the values to discover node 11

   $PPN_1 = PPN_1/g = 72{,}930/11= 6{,}630$

   $PPN_2 = PPN_2/g = 64{,}504/11 = 5{,}864$

   RN= [2, 3,5,13, 17]

   Remove the prime number [11] from RN and add it to RS

   RS= [11], INX= INX+1= 2

7. S_8, if PPN_1 is not a prime number: PPN_1= 6,630.

8. S_3, add one to the PPN_2: PPN_2= PPN_2 +1= 5,865

9. S_4, determine the GCD of PPN_1 and PPN_2:
   - g= GCS (PPN_1, PPN_2)= GCD(6630, 5865)= [255]
   - If g is not = 1 → g= 255
   - if g is not a prime number: g= 255, then S_7

10. S_7, this is the start of the "Bookmark Sub-procedure", as shown in Figure 8. At this point, gx= factors (255)= [17,5,3]. The process wants to find the right track by performing depth-first search. The procedure will consequently test the following tracks: track(1,1), track(1,2) and track(1,3). Figure 5d shows the possible three tracks:
    - Selecting [17] as a next node is track (1,1).
    - Selecting [5] as a next node is track (1,2).
    - Selecting [3] as a next node is track (1,3).

11. Next, the process moves forward following track (1,1) in order to find all the intermediate nodes in a particular order. Once S4 detects that the process is in a wrong track (g= 1), the backtrack procedure will stop and chooses the next track (e.g. track (1,2)). Figure 8 and figure 5d illustrates the testing of this track as in the following steps:

    Bmark(2,1) = 1, track(1,1)

    Bmark(2,2) = 3 , represents the number of various valid tracks at this bookmark point

    Bmark(2,3) = 6,630, PPN_1 at this point

    Bmark(2,4) = 5,865, PPN_2 at this point

Bmark(2,5) = 255 , g at this point

Bmark(2,6) = 1 , LB represents a Previous Bookmark

Forward(gx(Bmark(2,1))) → Forward(17) ,move the procedure forward

12. Move forward in the track (1,2) in order to find the intermediate node in particular order. Once S_4 detects that is a wrong track (g= 1 is true), backtrack procedure will stop and undertake the next track (e.g. track (1,3)). Figure 8 and figure 5d illustrates the testing of the track and how the sub-procedures behaviours will be.

    Bmark(2,1) = 2, track(1,2)

    Bmark(2,2) = 3 , represents the number of various valid tracks at this bookmark point

    Bmark(2,3) = 6,630, PPN_1 at this point

    Bmark(2,4) = 5,865, PPN_2 at this point

    Bmark(2,5) = 255 , g at this point

    Bmark(2,6) = 1 , LB represents a Previous Bookmark

    Forward(gx(Bmark(2,1))) → Forward(5) ,move the procedure forward

13. Move forward in the track (1,3) in order to find the intermediate node in particular order. Once S_4 detects that is a wrong track (g= 1 is true), backtrack procedure will stop and undertake a backward track (track(1)), because it is the last track at this bookmark. Figure 8 and figure 5d illustrates the testing of the track and how the sub-procedures behaviours will be.

    Bmark(2,1) = 3, track(1,3)

    Bmark(2,2) = 3 , represents the number of various valid tracks at this bookmark point

    Bmark(2,3) = 6,630, PPN_1 at this point

    Bmark(2,4) = 5,865, PPN_2 at this point

Bmark(2,5) = 255 , g at this point

Bmark(2,6) = 1 , LB represents a Previous Bookmark

Forward(gx(Bmark(2,1))) → Forward(3) ,move the procedure forward

14. In figure 5d, Now that the GCD of (PPN_1, PPN_2) is equal to one in all track(1) branches, i.e. the procedure decides it is the wrong track, and so chooses to progress along track(2). i.e. The right track will never give this result (GCD= 1) in S4, because at S8 the PPN_1 will be tested whether it is a prime number or not. If it is a prime number, then the backtrack procedure progress in the right track and it knows that this is the last prime number ("destination node"). However, if the PPN_1, in S8, is not a prime number, then the procedure will move forward. At this point, there is no indication if it is following a wrong or correct track, until S4 will test is reached again

15. The backtrack procedure will now chose the next possible track as follows, in this example, it is track(2):

    Bmark(1,1) = 2, track(2)

    Bmark(1,2) = 2 , represents the number of various valid tracks at this bookmark point

    Bmark(1,3) = 72,930 , PPN_1 at this point

    Bmark(1,4) = 64,504 , PPN_2 at this point

    Bmark(1,5) = 22 , g at this point

    Bmark(1,6) = 1 , LB represents a Previous Bookmark

    Forward(gx(Bmark(1,1))) → Forward(2) ,move the procedure forward.

16. S_6, the forward sub-procedure figure 9 moves forward by the following calculations:

    $PPN_1 = PPN_1/g= 72,930/2= 36,465$

$PPN_2 = PPN_2 /g = 64,504/2 = 32,252$

RN= [2, 3,5,13, 17]

Remove the prime number [2] from RN and add it to RS

RS= [2], INX= INX+1= 2

17. S_8, if PPN_1 is prime: No, PPN_1= 36,465.

18. S_3, add one to the PPN_2: PPN_2= PPN_2 +1= 32,253

19. S_4, determine the GCD of PPN1 and PPN_2:

    g= GCS (PPN_1, PPN_2)= GCD(36465, 32253)= [39]

20. In S_4,
    - If g= 1 → NO, (g= 39).
    - if g is a prime number: No, g= 39,
    - if g is not a prime number:, g= 39, then S_7

21.S_7 the Bookmark Sub-procedure and as shown in figure 8,

At this point, gx= factors (39)= [13,3]. The procedure will consequently test the following tracks: track(2,1) and track(2,2) . Figure 5d shows the procedure that should have chosen between two tracks.

- Selecting [13] as a next node is track (2,1).
- Selecting [3] as a next node is track (2,2).

22. The procedure should have chosen between two tracks, track(2,1) or track(2,2) while gx vector has been sorted in descending order, selecting the prime number will be in descending order also. As shown in figure 5d, selecting [13] as a next

node is track(2,1) while selecting [3] as a next node is track(2,2) if the first track(2,1) is wrong.

23. S_6, the forward sub-procedure figure 9 moves forward by doing these calculations:

    $PPN_1 = PPN_1/g= 36{,}465/13= 2{,}805$

    $PPN_2 = PPN_2 /g = 32{,}253/13 = 2{,}481$

    RN= [3,5,13, 17]

    Remove the prime number [13] from RN and add it to RS

    RS= [2,13], INX= INX+1= 3

24. In S_8, if PPN_1 is prime: No, PPN_1= 2,805.

25. In S_3, add one to the PPN_2: $PPN_2= PPN_2 +1= 2{,}482$

26. In S_4, determine the GCD of PPN_1 and PPN_2:

    g= GCS (PPN_1, PPN_2)= GCD(2805, 2482)= [17]

27. In S_4,
    - If g= 1 → NO, (g= 17).
    - if g is not a prime number, (g= 17).
    - if g is a prime number: Yes, g= 17,then S_6

28. In S_6, the forward sub-procedure, figure 9, moves forward by doing these calculations:

    $PPN_1 = PPN_1/g= 2{,}805/17= 165$

    $PPN_2 = PPN_2 /g = 2{,}482/17 = 146$

    RN= [3,5,17]

    Remove the prime number [17] from RN and add it to RS

    RS= [2,13,17], INX= INX+1= 4

29. Repeat above steps many times in order to get the final RS that represents Intermediate Route Nodes vector in particular order

    $PPN_1 = PPN_1/g = 165/3 = 55$

    $PPN_2 = PPN_2/g = 147/3 = 49$

    RN= [3,5]

    Remove the prime number [3] from RN and add it to RS

    RS= [2,13,17,3], INX= INX+1= 5

30. Repeat it again,

    $PPN_1 = PPN_1/g = 55/5 = 11$

    $PPN_2 = PPN_2/g = 50/5 = 10$

    RN= [5]

    Remove the prime number [5] from RN and add it to RS

    RS= [2,13,17,3,5], INX= INX+1= 6

31. In S_8, if PPN_1 prime number, YES $PPN_1 = 11$,

32. In S_9, add (11) to RS= [2,13,17,3,5,11] ,

33. In S_{10}, RS represents the highlighted route in figure 5c,6c in particular order.

Conclusion:

The examples described in this patent demonstrate the novelties of this new algorithm. The claims made are focused on using “Prime numbers” to be the address of the host portion of WMN node IP and accumulating “node knowledge” of the entire WMN. In this patent, the resultant “Prime-IP” claims have been proved mathematically and shown to work for multi-hop dynamic topology WMNs.

CLAIMS

1. A method of routing and node addressing in a wireless mesh network (WMN) including a plurality of wireless nodes, each node having an IP address with a host portion and a network portion, the method producing a unique routing path from a source node to a destination node through intermediate nodes, the method comprising the steps of:

assigning a unique a prime number in the host portion of the IP address of each individual node, the prime number of the destination node being Pd;

the source node issuing a "route request packet" (RREQ) which is sent to the destination node via various route options;

on receipt of the RREQ, the destination node issuing a "route reply packet" (RREP) which is returned to the source node via various route options, wherein the respective RREP for the destination node and for each intermediate node includes two number fields PPN_1 and PPN_2 that are calculated from the prime numbers assigned to the individual nodes in the WMN, wherein for each route option:

the value of PPN_1 for the destination node is Pd and the value of PPN_2 for the destination node is (Pd-1);

the value of PPN_1 for a first neighbouring intermediate node in the route option is calculated by multiplying the unique prime number assigned to the first neighbouring intermediate node by Pd, and the value of PPN_1 for any subsequent neighbouring intermediate node in the route option is calculated by multiplying the unique prime number assigned to the subsequent neighbouring intermediate node by the value of PPN_1 for the previous intermediate node in the route option; and the value of PPN_2 for a first neighbouring intermediate node in the route option is calculated by multiplying the unique prime number assigned to the first neighbouring intermediate node by (Pd-1) and subtracting 1, and the value of PPN_2 for any subsequent neighbouring intermediate node in the route option is calculated by multiplying the unique prime number assigned to the subsequent neighbouring intermediate node by the value of PPN_2 for the previous intermediate node in the route option and subtracting 1;

carrying out a backtrack procedure using the values of PPN_1 and PPN_2 received by the source node to generate, for each route option, a vector RS containing the unique prime numbers allocated to the destination node and the intermediate nodes in a particular order; and

using the vectors RS to select the optimum available route between the source node and the destination node.

2. A method according to claim 1, wherein, for each route option, the backtrack procedure includes the steps of:

(a) factorising the value of PPN_1 received by the source node for a particular route option to determine a vector RN containing the unique prime numbers allocated to the destination node and the intermediate nodes in the particular route option in no particular order;

(b) adding 1 to the value of PPN_2 received by the source node for the particular route option to determine a new value of PPN_2;

(c) determining the greatest common divisor (GCD) for the value of PPN_1 received by the source node and the new value of PPN_2; and

(d) carrying out one of the following steps:

a forward sub-procedure if the GCD is a prime number, wherein the forward sub-procedure includes the steps of:

removing from the vector RN the prime number that matches the GCD of step (c); and

selecting as the first or next subsequent prime number of the vector RS the prime number that matches the GCD of step (c);

a bookmark sub-procedure if the GCD of step (c) is not a prime number; and

a backward sub-procedure if the GCD of step (c) equals 1.

3. A method according to claim 2, wherein the forward sub-procedure further includes the steps of:

dividing the value of PPN_1 by the GCD of step (c) to determine a new value of PPN_1 and dividing the value of PPN_2 by the GCD of step (c) to determine a new value of PPN_2; and

if the new value of PPN_1 is a prime number, selecting PPN_1 as the last unique prime number of the vector RS, otherwise repeating steps (b) to (d) using the value of new value of PPN_2 in place of the value of PPN_2 received by the source node for the particular route option in step (b) and the new value of PPN_1 in place of the value of PPN_1 received by the source node in step (c).

4. A method according to claim 2, wherein the bookmark sub-procedure further includes the steps of:

determining the factors of the GCD of step (c), each factor representing a different valid track;

selecting a factor to select a valid track; and

carrying out a forward sub-procedure that includes the steps of:

removing from the vector RN the prime number that matches the selected factor;

selecting as the first or next subsequent prime number of the vector RS the prime number that matches the selected factor;

dividing the value of PPN_1 by the selected factor to determine a new value of PPN_1 and dividing the value of PPN_2 by the selected factor to determine a new value of PPN_2; and

if the new value of PPN_1 is a prime number, selecting PPN_1 as the last unique prime number of the vector RS, otherwise repeating steps (b) to (d) using the value of new value of PPN_2 in place of the value of PPN_2 received by the source node for the particular route option in step (b) and the new value of PPN_1 in place of the value of PPN_1 received by the source node in step (c).

5. A method according to claim 4, wherein the backward sub-procedure includes the steps of:

adding to the vector RN one or more factors of the previously selected valid track that were removed from the vector RN in a previous forward sub-procedure;

removing from the vector RS the one or more factors of the previously selected valid track that were added to the vector RS in a previous forward sub-procedure;

selecting a different factor to select a different valid track; and

carrying out a forward sub-procedure that includes the steps of:

removing from the vector RN the prime number that matches the selected factor; and

selecting as the first or next subsequent prime number of the vector RS the prime number that matches the selected factor;

dividing the value of PPN_1 by the selected factor to determine a new value of PPN_1 and dividing the value of PPN_2 by the selected factor to determine a new value of PPN_2; and

if the new value of PPN_1 is a prime number, selecting PPN_1 as the last unique prime number of the vector RS, otherwise repeating steps (b) to (d) using the value of new value of PPN_2 in place of the value of PPN_2 received by the source node for the particular route option in step (b) and the new value of PPN_1 in place of the value of PPN_1 received by the source node in step (c).

6. A method according to any preceding claim, wherein the IP address of each individual node is an IPv4 or an IPv6 address type.

7. A method according to any preceding claim, wherein the WMN is a multi-hop wireless network.

8. A method according to any preceding claim, wherein the wireless nodes are fixed nodes or mobile nodes.