Opportunistic Routing in VANETs

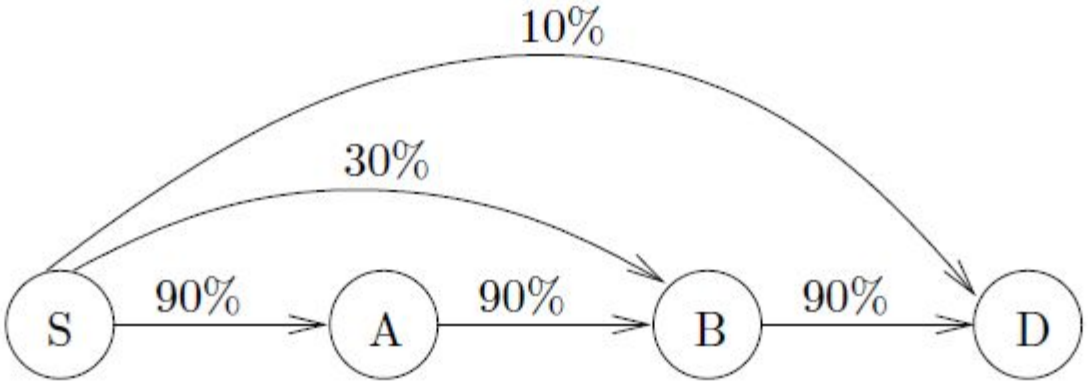
ETX-EAX

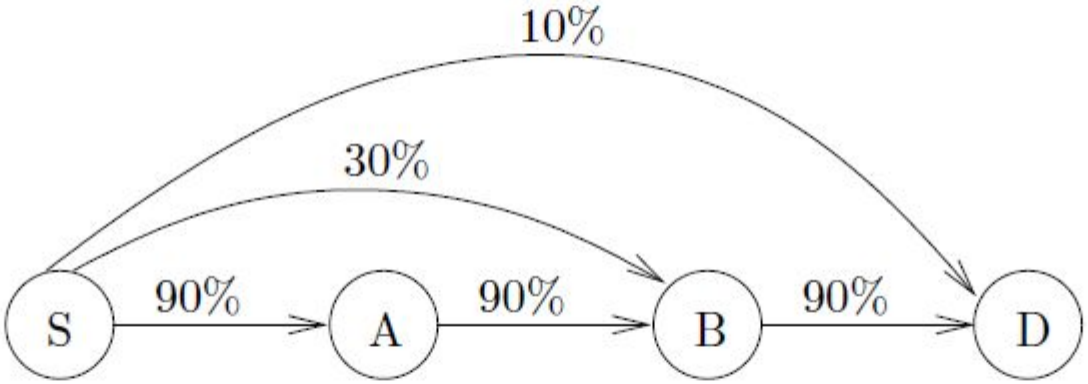
—**Expected Transmission Count (ETX)** measures the number of times that a packet must be transmitted/retransmitted, on average, at a link or on route, to be received by the designated node.

The transmission of packets between nodes i and j is here assumed to be the Bernoulli trail, which has $p_{i,j}$ as the link delivery probability between two nodes i and j; therefore, the ETX of the corresponding link is:

$$ETX(i, j) = \frac{1}{p_{i,j}}. \tag{3}$$

ExNT: Expected Number of Transmission

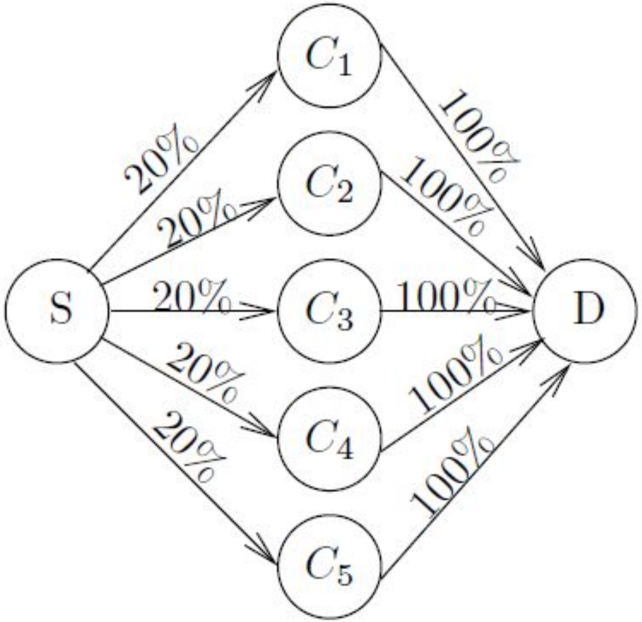

10%
30%
90%
90%
90%
S
A
B
D

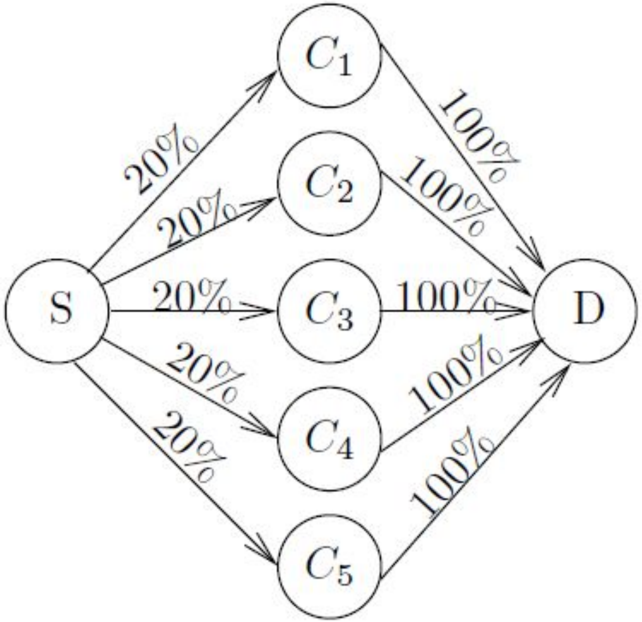


S-D= 10 2.22 1.11 0

S-B-D= 4.4

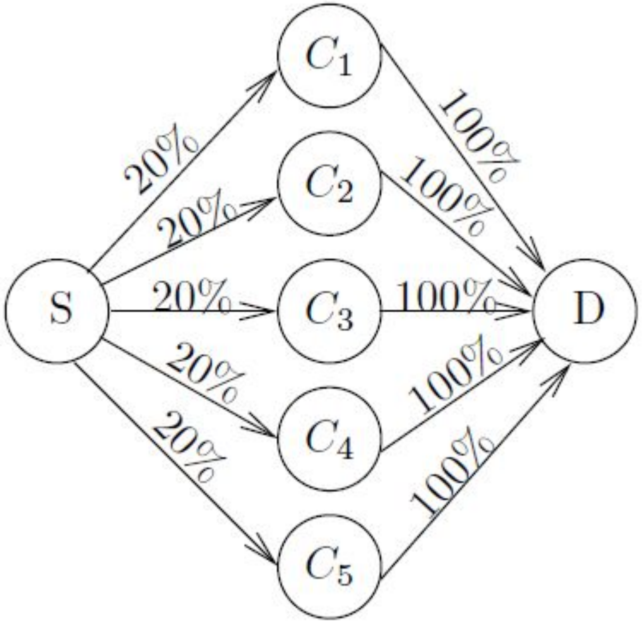
S-A-B-D= 3.33


S
C_1
C_2
C_3
C_4
C_5
D
20%
20%
20%
20%
20%
100%
100%
100%
100%
100%

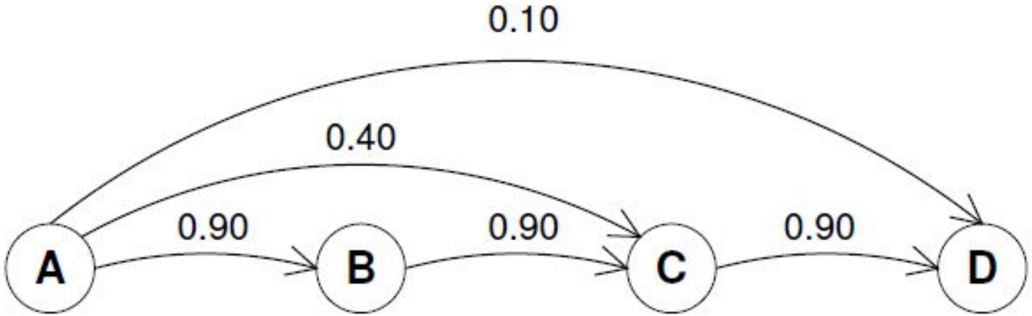


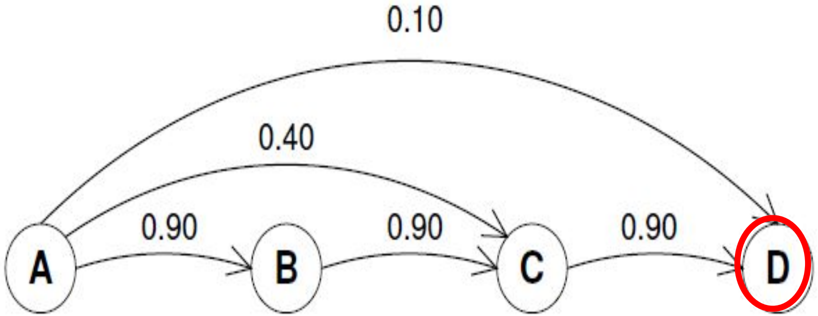
1-((1-0.2)(1-0.2)(1-0.2)(1-0.2)(1-0.2))= 0.67 or 67%

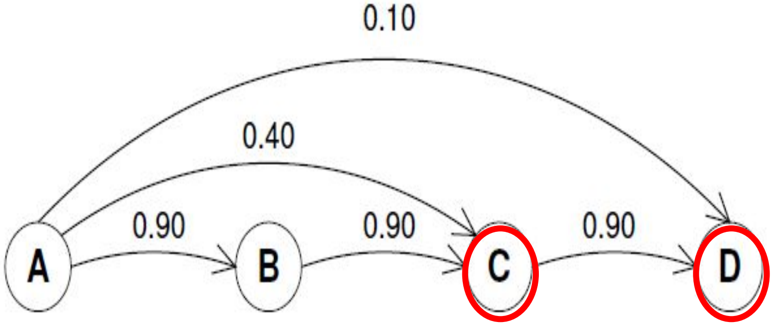
1/0.67= 1.48, 1/1=1 => 1.48+1=> 2.48

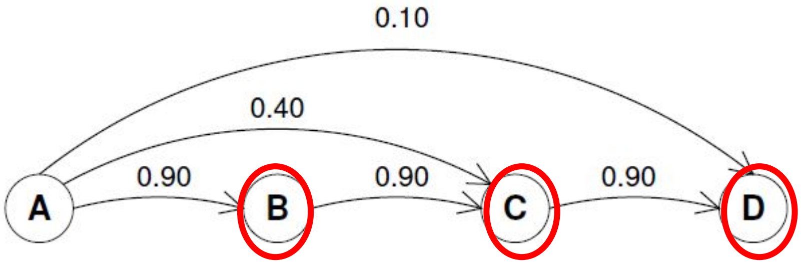


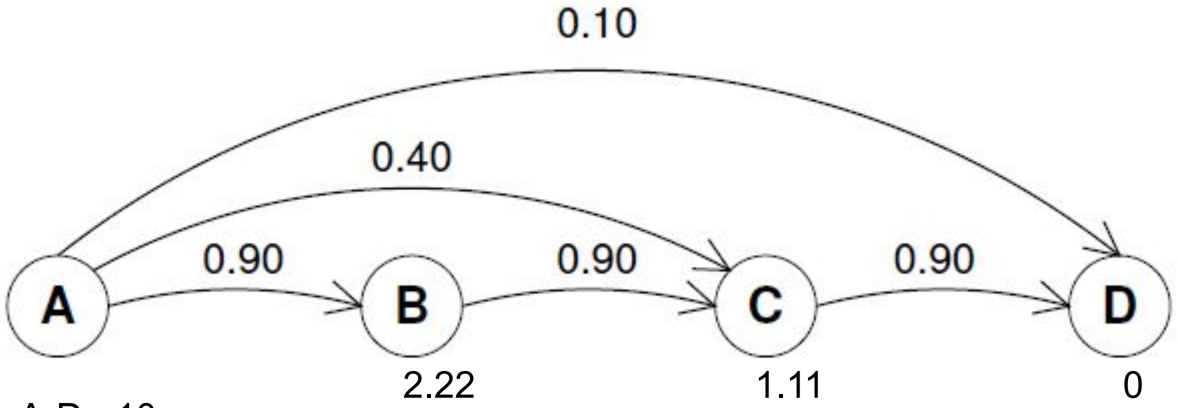
Under a traditional routing protocol, we have to pick one of the five intermediate nodes as the relay node. Thus, altogether we need 5 transmissions on average to send a packet from the source to the relay node and 1 transmissions from the relay node to the destination. In comparison, under OR, we can select the five intermediate nodes as the candidates. The combined link has a success rate of $(1 - (1 - 20\%)^5) = 67\%$. Therefore, on average only 1/0.67 = 1.48 transmissions are required to deliver a packet to at least one of the five candidates, and another transmission is required for a candidate to forward the packet to the destination, so on average it takes only 2:48 transmissions to deliver a packet to the destination.


0.10
0.40
0.90
0.90
0.90
A
B
C
D

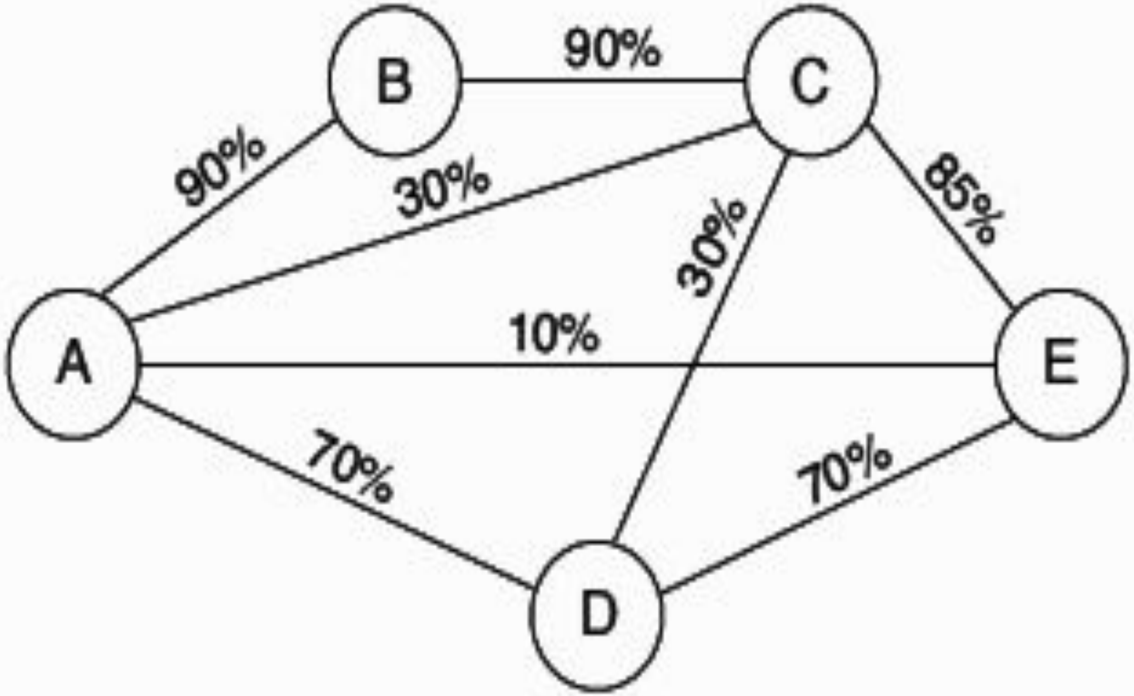

0.10
0.40
0.90
0.90
0.90
A
B
C
D

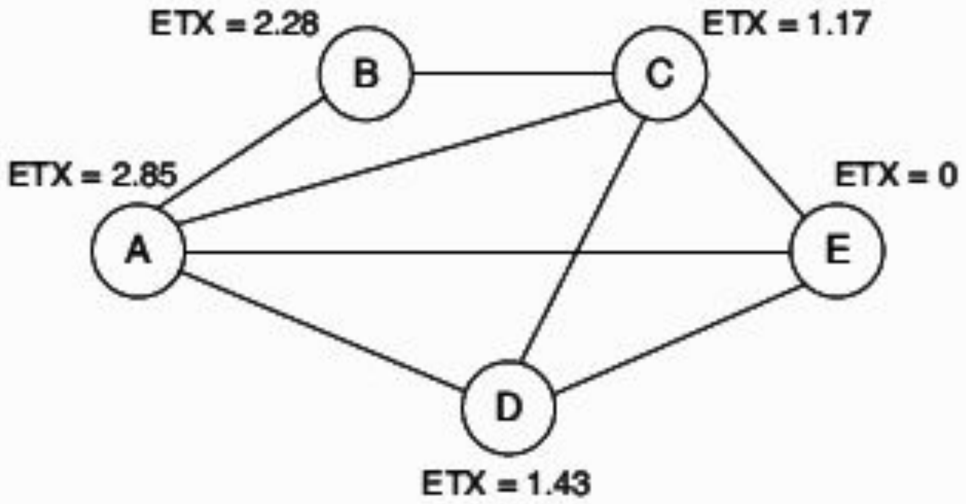

0.10
0.40
0.90
0.90
0.90
A
B
C
D

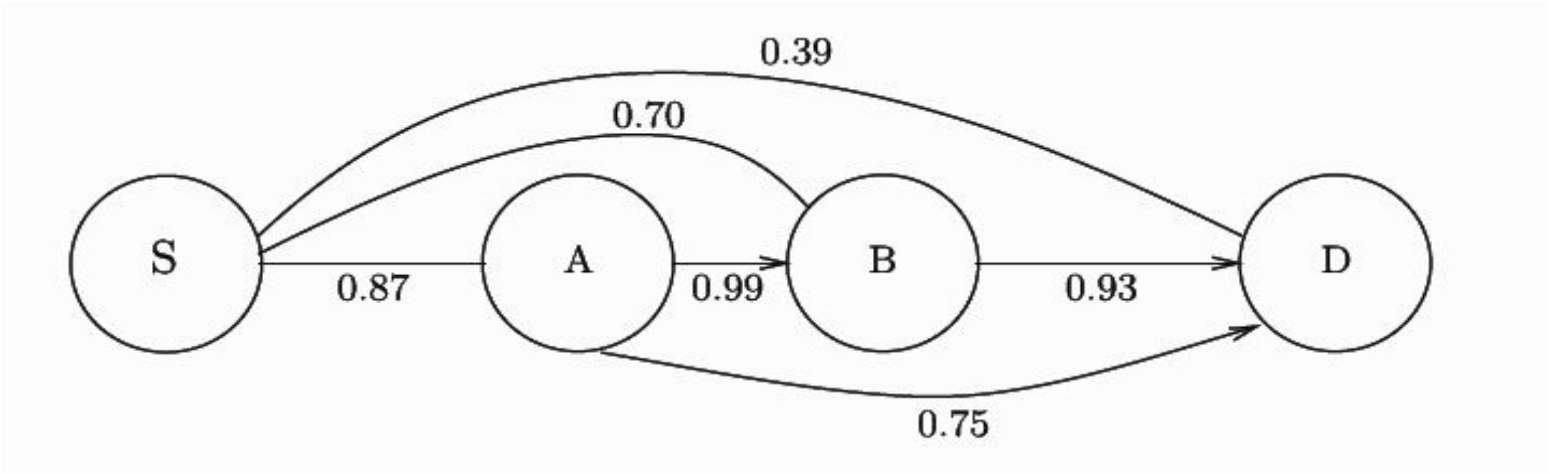

0.10
0.40
0.90
0.90
0.90
A
B
C
D



A-D =10
A-C-D= 3.61
A-B-C-D=3.33


A
B
C
D
E
90%
90%
30%
30%
85%
10%
70%
70%


ETX = 2.28
B
C
ETX = 1.17
ETX = 2.85
ETX = 0
A
E
D
ETX = 1.43



S-A_B= 1.14+1.01= 2.15

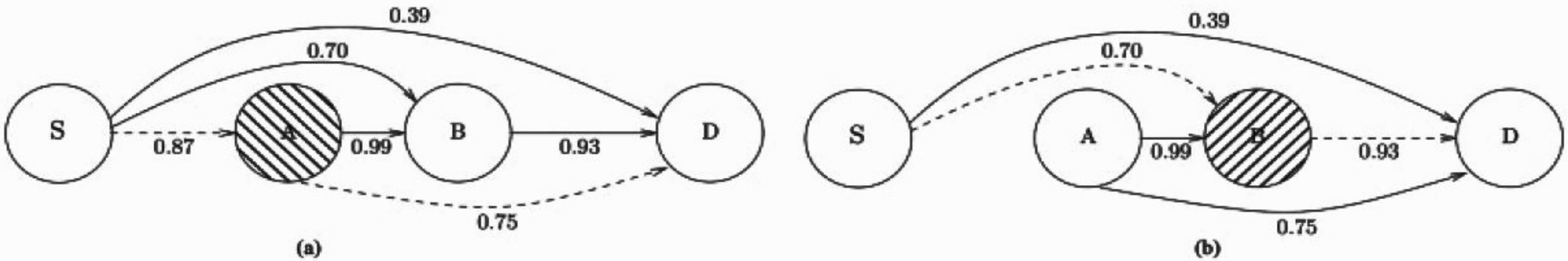
s-B= 1.4

S-B-D= 2.49, 2.47,
S-A-D=2.47, 2.58,

S-D

1. S-D= 1/0.39= 2.56
2. S-B-D= 1/0.7+1/0.93= 1.42+1.07= 2.49
3. S-A-D= 1/0.87+1/0.75= 1.14+1.33= 2.47
4. S-A-B-D= 1/0.87+1/0.99+1/0.93= 1.14+1.01+1.07= 3.22

Node	ETX(Node, D)
S	2.48
A	1.33
B	1.07
D	0



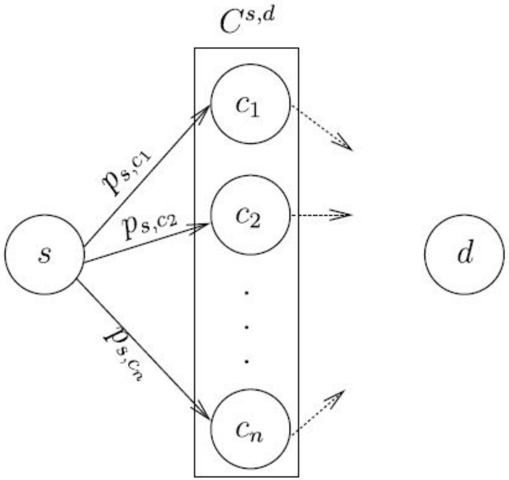


Fig. 3. Expected Any-path Transmission (EAX) calculation.

Let s and d be the source and destination nodes, respectively. Furthermore, assume that $C^{s,d}$ is the CS used to reach the destination d from node s. The probability that a packet transmitted by s can reach at least one of the candidates in $C^{s,d}$ is $1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})$. Therefore, the ExNT needed to deliver a packet from source s to at least one of its candidates in $C^{s,d}$ is given by:

$$S(C^{s,d}, s, d) = \frac{1}{1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})}. \quad (5)$$

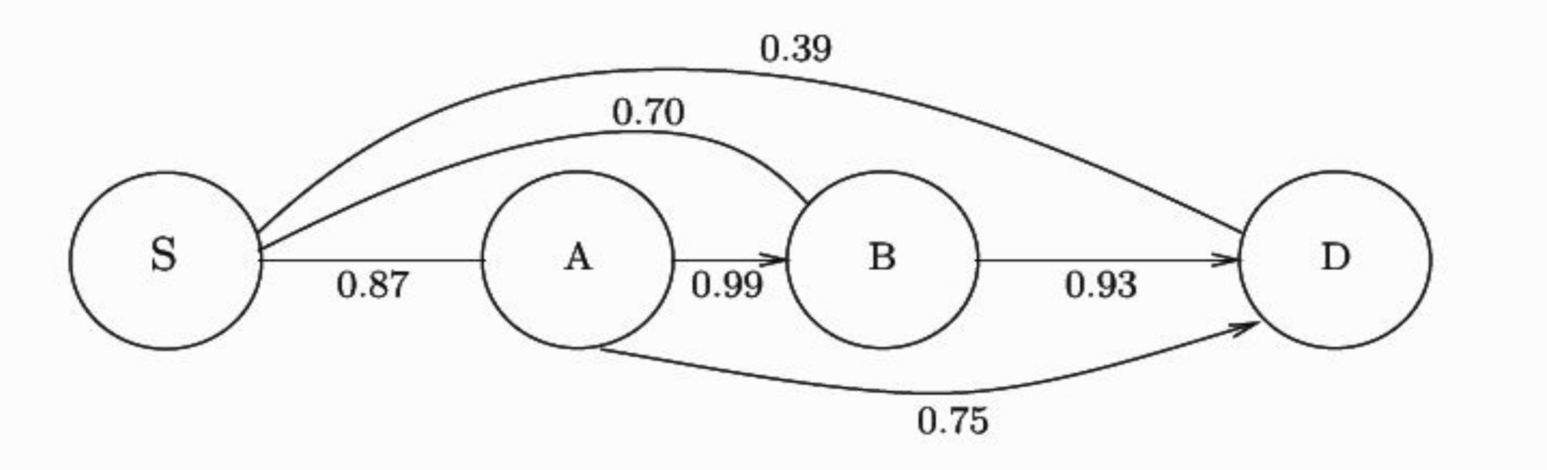
After a node(s) in the CS of s receives the packet, the candidate with the highest priority is responsible for forwarding the packet. The ExNT used to reach the destination d from one of the nodes in $C^{s,d}$, which is responsible for forwarding the packet, is depicted through the following equation:

$$Z(C^{s,d}, s, d) = \frac{\sum_{i=1}^{|C^{s,d}|} EAX(C^{c_i,d}, c_i, d)\, p_{s,c_i} \prod_{j=1}^{i-1}(1 - p_{s,c_j})}{1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})}. \tag{6}$$

Note that in Equation (6), the product $\prod_{j=1}^{i-1}$ is equal to 1 for $i = 1$. Furthermore, node c_i acts as the next-hop forwarder if none of its previous candidates ($\{c_1, c_2, \ldots, c_{i-1}\}$) receives the packet successfully. Using the same assumptions as in Equation (3), the ExNT needed to reach destination d from s can be calculated; this is done by summing up the number of transmissions from the source to its CS ($S(C^{s,d}, s, d)$) and the number of transmissions from CS to the destination ($Z(C^{s,d}, s, d)$), given by the recursive formula:

$$EAX(C^{s,d}, s, d) = S(C^{s,d}, s, d) + Z(C^{s,d}, s, d). \tag{7}$$

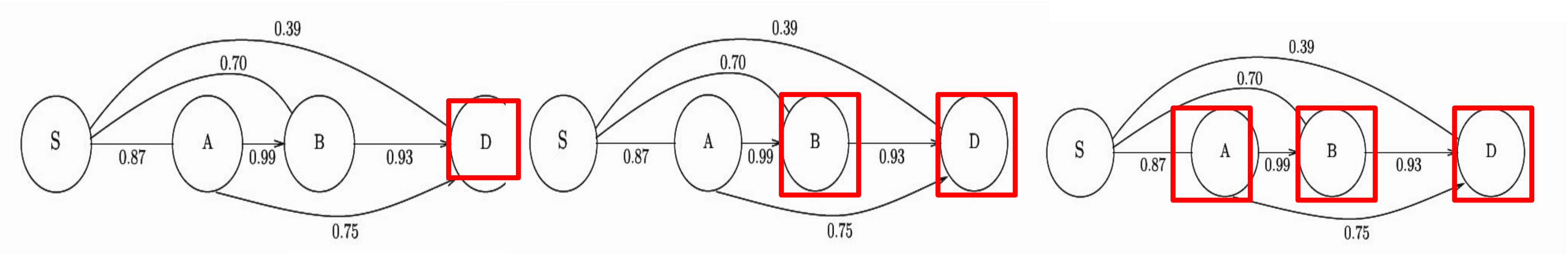
Due to the recursive nature of EAX formula, the cost of calculating EAX in a large network with a great number of candidates is very high. But, on the other hand, the ExNT for the candidate selection algorithms that use EAX is better than those that use ETX [Darehshoorzadeh and Cerdà-Alabern 2010; Darehshoorzadeh et al. 2011].



1/(1-(1-0.7))+1/(1-(1-0.93)

1/(1-(1-0.75) = 1.33

1/(1-(1-0.87)+1.26 = 2.41



Node	Candidates Set	EAX
A	$\{D, B\}$	1.26
B	$\{D\}$	1.07

$EAX(\{A\}, S, D) = 2.41,$ $EAX(\{B\}, S, D) = 2.50,$ $EAX(\{D\}, S, D) = 2.56$

=1/(1-(1-0.70))+1/(1-(1-0.93)) **=1/(1-(1-0.39))**

$$S(C^{s,d}, s, d) = \frac{1}{1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})}.$$

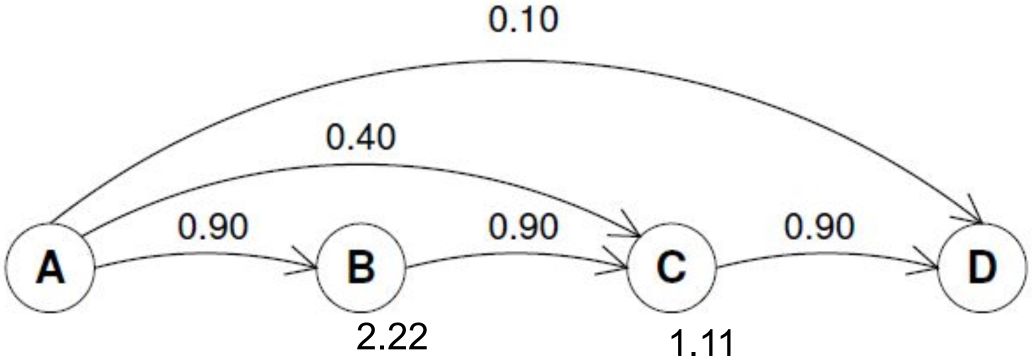
=1/(1-(1-0.93)(1-0.99))

$$Z(C^{s,d}, s, d) = \frac{\sum_{i=1}^{|C^{s,d}|} EAX(C^{c_i,d}, c_i, d)\, p_{s,c_i} \prod_{j=1}^{i-1}(1 - p_{s,c_j})}{1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})}.$$

.33*0.99*(1-0.93)/(1-(1-0.99)(1-0.93))

$$EAX(C^{s,d}, s, d) = S(C^{s,d}, s, d) + Z(C^{s,d}, s, d).$$

=1.07+0.19 = 1.26



$A\text{-}D = 1/(1-(1-0.10)=10$

$A\text{-}C\text{-}D = 1/(1-(1-0.40)+1/(1-(1-0.90))$

$=3.61$

$A\text{-}B\text{-}C\text{-}D = 1/(1-(1-0.90)+$

$1/(1-(1-0.90)+$

$1/(1-(1-0.90)$

3.33