Reliable Coverage Area Based Link Expiration Time (LET) Routing Metric for Mobile Ad Hoc Networks

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Abstract. This paper presents a new routing metric for mobile ad hoc networks. It considers both coverage area as well as link expiration information, which in turn requires position, speed and direction information of nodes in the network. With this new metric, a routing protocol obtains routes that last longer with as few hops as possible. The proposed routing metric is implemented with Ad Hoc On-Demand Distance Vector Routing (AODV) protocol. Thus, the performance of the proposed routing metric is tested against the minimum hop metric of AODV. Simulation results show that the AODV protocol with the new routing metric significantly improves delivery ratio and reduces routing overhead. The delay performance of AODV with the new metric is comparable to its minimum hop metric implementation.

Keywords: Mobile ad hoc network routing, Link Expiration Time, reliable coverage area, AODV.

1 Introduction

As nodes are deployed randomly in ad hoc networks, they need to form and maintain a network automatically. Thus, the role of a routing algorithm becomes crucial [1, 2] in such networks. Node mobility increases complexities of routing even further due to frequent link breakages. These link breakages increase routing control overhead and reduce efficiency of the network due to the increased frequency of the route discovery process; therefore, treatment of link breakages in Mobile Ad hoc Networks (MANETs) is very important. There are a number of proposals in the literature to address this problem. Reference [3] proposes Associativity-Based Routing (ABR) in which each node periodically transmits beaconing ticks to identify itself. The metric used for route selection is the number of ticks received at the receiving node. If a large number of ticks are received, then the route is considered stable. However, there is a substantial increase in overhead in ABR due to these periodic beaconing signals. Another adaptive protocol is Signal Stability-Based Adaptive Routing (SSA) [4] which uses signal strength as a metric to select the most reliable route. It selects links with higher signal strength. However, higher signal strength is an indication of shorter distance between two nodes. Therefore, nodes close to each other in the route selection process will increase the hop count between the source and the destination,

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which in turn increases end-to-end delay in the network. References [5] and [6] present an algorithm that is useful for link stability estimation when the node's movements are random. Link properties in this algorithm are based on a random way point mobility model. Reference [7] presents an algorithm that analyses the link lifetime and expected link change rate of MANETs by using a distance transition probability matrix. Link properties in this algorithm are based on the smooth mobility model. The algorithms, mentioned in [5, 6] and [7], are based on probabilistic approaches. The reliable distance based routing metric for reliable route selection in the AODV protocol is investigated in [8]. Neighboring nodes that lie farther than reliable distance (which is less than transmission range) are not considered during route selection by a node. As links between the nodes present within a reliable distance are still decided on the basis of the minimum hop criteria of AODV, thus this metric tries to select the next hop neighbor that lies near the periphery of the reliable distance region of a node. Therefore, the chances of early breakage of a route increase greatly even with a small increase in the relative speed of mobile nodes.

That is why the routing metric in MANETs' routing protocol needs to co-operate with location as well as mobility. In this context, this paper presents a new reliable coverage area (RCA) based LET routing metric. This metric helps in selecting reliable as well as relatively more stable links. The outer periphery of RCA helps to avoid frequent link breakage by avoiding nodes on the edge of transmission range, while the inner periphery of RCA helps to minimize end-to-end delay by avoiding closely spaced nodes. This routing decision scheme is implemented in the AODV protocol, and is tested via simulations.

The remainder of the paper is organized as follows. Section 2 surveys related studies and provides background. Section 3 presents a description of the proposed routing metric. Simulation environment information and results are presented in section 4. Finally, conclusions are presented in Section 5.

2 Related Work

2.1 AODV Overview

Ad Hoc on Demand Distance Vector (AODV) is one of the most promising reactive routing protocols [9]. The proposed routing metric was tested on AODV and performance of the new metric is measured against the minimum hop metric. AODV uses four sets of messages, namely route request (RREQ), route reply (RREP), route error (RERR) and periodic beacons (HELLO). The route discovery mechanism is initiated on demand from a source node to reach to a destination node using RREQ. The neighboring nodes will re-broadcast RREQ during time slot $[0ms, 10ms]$ randomly. As RREQ propagates through the network, a reverse path is created by intermediate nodes towards the source node. The RREP message is generated by the destination node when it receives the RREQ or by the intermediate node if this intermediate node has a fresh route toward the destination. The route error (RERR) message is used when there is a link breakage. AODV relies on medium access control layer messages to identify route errors. HELLO messages are used for monitoring the link status among the neighboring nodes. AODV uses a single path in its routing table for each destination.

2.2 Coverage Area Analysis

An additional coverage area analysis is comprehensively presented in [10] for a static network. In this subsection, we describe some of those results that are pertinent to our work. The additional area coverage depends on the distance between two nodes and the transmission radius. Fig. 1 illustrates this dependency between the distance and transmission radius. Let us consider two nodes A and B located at a distance of d meters (m) apart, and their transmission radii is r (m).

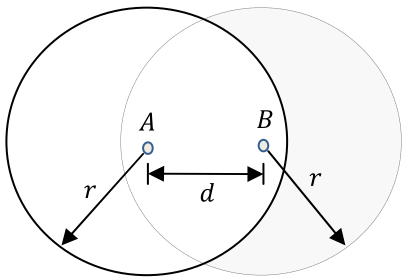

Fig. 1. Coverage area analysis for static network

Here, A is sending a message and B is forwarding this message. Let S_A and S_B be the area covered by the nodes A and B, respectively. The additional area that node B can cover is shaded, denoted by S_{B-A}, and given by

$$|S_{B-A}| = |S_B| - |S_{A \cap B}| = \pi r^2 - INTC(d) . \quad (1)$$

Here, $INTC(d)$ is the intersection area of two circles centered at two points located at a distance of d apart, and is given by

$$INTC(d) = 4 \int_{d/2}^{r} \sqrt{r^2 + x^2} \, dx . \quad (2)$$

For $d = r,$ the additional coverage is the largest, and is given by

$$\pi r^2 - INTC(r) = r^2 \left(\frac{\pi}{3} + \frac{\sqrt{3}}{2} \right) \approx 0.61 \pi r^2 . \quad (3)$$

Equation (3) shows that a node lying at the edge of transmission range of the previous node can provide an additional 61 percent coverage over what has already been covered by the previous node.

The above discussion is valid for static networks. However, mobile networks offer different challenges. Fig. 2 illustrates the effect of mobility on an additional coverage area. Forwarding node (FN_c), located inside the transmission radius of mobile node (MN), provides the largest additional coverage for MN's messages. However, being a border node, it can move out of transmission range of MN any time, and how long it can serve for MN depends on its relative speed and direction.

In contrast to this, being close to MN, FN_a provides less additional coverage area, but it can remain in contact with MN for a longer period of time. Similarly, FN_b is

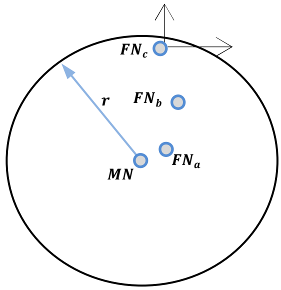

Fig. 2. Coverage scenario under mobility

located in the middle of transmission range of MN; thus, it gives a compromise between additional coverage area and time to remain in contact with MN. This tradeoff is investigated further in selecting the forwarding node in Section 3.

2.3 Link Expiration Time

The Link Expiration Time (LET) is the time for which two mobile nodes can remain in contact with each other. To find the estimated LET in our proposed routing metric, we used the following formula as given in Reference [11],

$$Dt = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)r^2 - (ad - bc)^2}}{a^2 + c^2} \tag{4}$$

Here, $a, b, c \ and \ d$ are given as follows:-

$$a = vicos\theta i - vjcos\theta j$$
$$b = xi - xj$$
$$c = visin\theta i - vjsin\theta j$$
$$d = yi - yj$$

Here, i and j are two mobile nodes that have r (m) as their transmission or LOS range, vi and vj are their velocities, θi and θj are their direction of motion, and (xi, yi) and (xj, yj) are their positions respectively. This information can be obtained if the mobile nodes are equiped with a GPS system.

3 Proposed Routing Metric Description

This section presents a description of our RCA based LET routing metric. This metric assumes that all the nodes have the same transmission radius and are equipped with GPS systems.

The proposed routing metric can be explained with the help of Fig. 3. In this figure, the transmission range of a mobile node, r, is virtually divided into three regions. The internal region between R_{min} and R_{max} is referred to as *reliable coverage area*. The

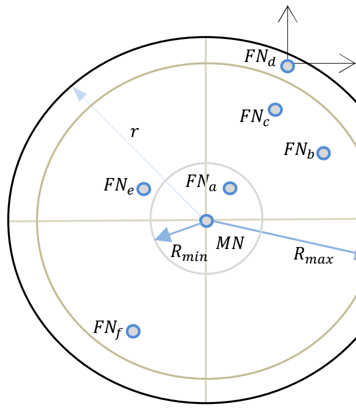

Fig. 3. Transmission regions of a mobile node

nodes present in this region are considered as reliable and stable nodes in terms of additional area coverage and LET. The outer region between R_{max} and r is considered as *unreliable coverage area* in terms of LET. The innermost region between R_{min} and the position of MN is considered as an *undesirable coverage area,* in terms of length of route since nodes in this region increase hop count without providing any significant additional coverage area, as per the discussion in Section 2.2. The value of R_{min} depends on the compromise between acceptable delay and longevity of a route. However, value of R_{max} depends upon the wireless medium characteristic and the mobility model. The value of these parameters can be tuned to provide desired performance for an application in MANETs.

The central theme of our routing metric is that the nodes that lie in an RCA are given the first priority in route selection. However, nodes in an unreliable coverage area and undesirable coverage area are given second and third priority respectively in route formation. A priority scheme is implemented using the concept of waiting interval prior to re-broadcasting of the RREQ message. For example, from Fig 3, if MN sends a route request, then the nodes in its RCA (FN_c, FN_b, FN_e and FN_f) respond to that request in a randomly allocated time slot of $[0ms, 5ms]$. Upon hearing a re-broadcast from nodes in RCA during $[0ms, 5ms]$, the nodes lying in unreliable and undesirable coverage areas (FN_d and FN_a respectively) do not respond to route request. Thus, they do not take part in route selection. This helps to avoid unnecessary re-broadcast of RREQ from an unreliable and undesirable coverage area, which in turn significantly reduces routing overhead in the network. However, if there is no node in the reliable region, then, nodes from the unreliable coverage area respond to route request from MN in the next time slot of $[5ms, 10ms]$. Similarly, if there are no nodes lying in the RCA and unreliable coverage area, then nodes from the undesirable coverage area respond to route request in the next time slot of $[10ms, 15ms]$.

A node calculates its LET value on the basis of its link status with its previous hop node, as given in equation (4). Thus, the source does not have a valid LET value as it does not have any previous hop node. Therefore, when the route discovery mechanism is initiated by the source node MN, the source node broadcasts an RREQ packet with a dummy high value of LET. In general, after receiving an RREQ, an intermediate node calculates its distance from the previous hop node as well as the LET value of the link between itself and the previous hop node. Thus, the nodes from the RCA of the source node calculate their own LET values and compare them with LET value of the just received RREQ packet from the source node. They retain the minimum of these two LET values. Then, these nodes re-broadcast the RREQ packet within $[0ms, 5ms]$ time slot by inserting the minimum LET values in their respective RREQ packet headers. Here, each of the nodes from the RCA of the source node, which takes part in a re-broadcast process, acts as an MN node and the group of nodes from their respective RCAs respond to their RREQ packets. This process continues until an RREQ packet reaches its destination. The destination node also calculates its own LET value and compares this value with that of the just received LET value and retains the minimum of these two LET values. Thus, the destination node now has the minimum LET value of the path between itself and the source node. The destination node inserts this minimum value of LET for the path in the route reply (RREP) packet and sends it back towards the source node.

This routing metric always gives emphasis to the best LET value path achieved from the nodes that are present in the RCA. However, if two or more paths have the same LET value, then the path with the lower hop count is chosen. Thus, if the destination node receives an RREQ packet from a different path with a better LET value, then it regenerates the RREP packet and sends it to the source node. After receiving the RREP, the source node updates its routing table and starts sending data packets through the new path.

Fig. 4 shows a typical route selection scenario. In this figure, node A initiates a route discovery mechanism. Node B and C are present in the RCA of node A. Node D is present in the RCA of both B and C. After receiving a broadcast request from A, B calculates the LET value (minimum) and sends it to D. Then, D compares the just received LET value from B with its own calculated LET value. The node keeps the minimum of these two LET values and inserts it into the RREQ packet header and holds this packet for its random allocated time slot of duration $[0ms, 5ms]$. Meanwhile, before re-broadcast, if D receives a request packet from C, then it compares the just received LET value from C with its own calculated LET value. Thus, if the minimum of the LET values with C is higher than the minimum of the LET values with B (as calculated previously), then discards the path through node B and adopts a path though node C. In this way, the intermediate nodes on the way towards the destination will keep on selecting the best possible path in terms of higher LET values.

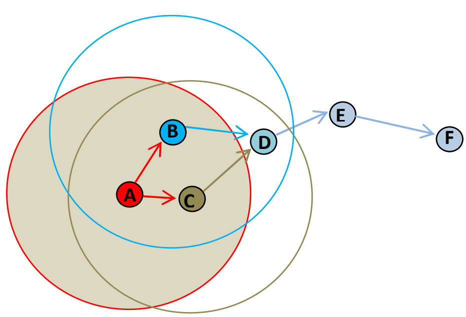

Fig. 4. A typical route selection scenario

4 Simulation Environment and Results

The performance of the proposed routing metric has been tested by using an NS-2 simulator. Constant Bit Rate (CBR) traffic sources are used in the simulation with a packet size of 512 bytes and data rate of 4 packets per second. The network is composed of 30 nodes moving around a flat rectangular area of 1500m x 300m, where 3 nodes are chosen to be UDP sources and another 3 nodes are chosen as destination nodes. The channel bandwidth is taken as 2 Mbps. The transmission range of a node is taken as 250 meters. IEEE 802.11 wireless network standard with Distributed Coordination Function (DCF) mode is used for the MAC layer. Simulation time is taken as 400 seconds. Each data point is taken as an average of 15 runs. The developed routing metric has been integrated in ad hoc on demand routing (AODV).

In the real world, MNs such as cars cannot roam freely due to obstacles and traffic regulations. Thus, such MNs have more or less similar patterns of travelling in any part of a city. To represent such a mobile scenario, we took the Manhattan Grid mobility model [12] in the simulation. For creating this mobility model, Bonnmotion v1.3a [12] and 13] tool is used. In our simulation scenario, MNs are moving at a mean speed (represented as v) of 1 m/s, 10 m/s, 20 m/s, 30 m/s, 40 m/s, and 50 m/s. A grid of ten horizontal and two vertical blocks are taken. The movement update distance is taken as 20 meters. Both the turn and speed change probabilities are taken as 0.1. The minimum and maximum speeds are taken as 0.9v and 1.1v.

In the following discussion, AODV(NM) represents AODV protocol modified with the proposed routing metric. We compared the performance of traditional AODV and AODV(NM) on the basis of four performance metrics. These are given as below.

- Packet Delivery Ratio: It is the ratio of data packets received by destination to those generated by a CBR source.
- Number of RERRs: It is the total number of RERR packets during a simulation run. It gives information about frequency of route breakage.
- Normalized routing overhead: It is the number of control packets (RREQ in this case) transmitted or forwarded by all nodes per data packet delivered to destinations.
- Average end-to-end Delay: It is the average of durations taken by data packets to reach from their sources to their destinations.

As shown in Fig. 5, the packet delivery ratio of AODV(NM) is better than traditional AODV, particularly at higher relative speeds of MNs. It is due to the fact that the traditional AODV experiences frequent route breakage with increasing relative speeds of nodes, as the route selection decision in traditional AODV is based on minimum hop routing only. It does not consider the link expiration aspect of a route. Thus, routes selected by AODV break quite frequently as relative speeds of MNs increase. In contrast to this, AODV(NM) uses link expiration information to select a route. Therefore, though the number of hops in a selected route may be higher in AODV(NM) than that of AODV, the route in our case will last longer which results in a higher packet delivery ratio.

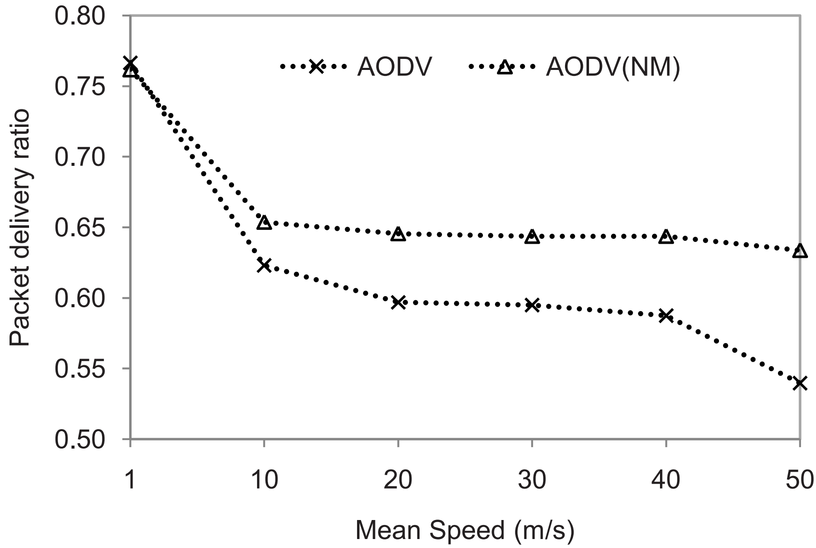

Fig. 5. Packet Delivery ratio vs. Mobility

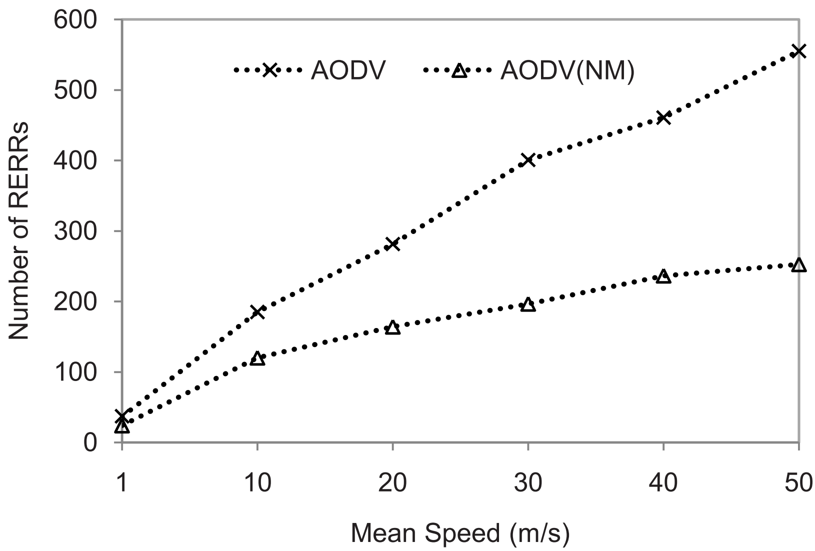

Fig. 6. Number of RERRs vs. Mobility

This argument is further confirmed by observing the number of RERR packets in the network. Fig. 6 shows that rate of increase in frequency of route breakage with respect to increasing relative speeds of MNs is more in the case of traditional AODV as compared to AODV(NM).

As shown in Fig. 7, rate of increase in normalized routing overhead is less in AODV(NM) because AODV(NM) uses the reliable coverage area concept to determine which nodes take part in route selection. Thus, the number of nodes that take part in route selection is lower in AODV(NM) as compared to traditional AODV which is based on random broadcast for route selection. It reduces flooding in the network in AODV(NM).

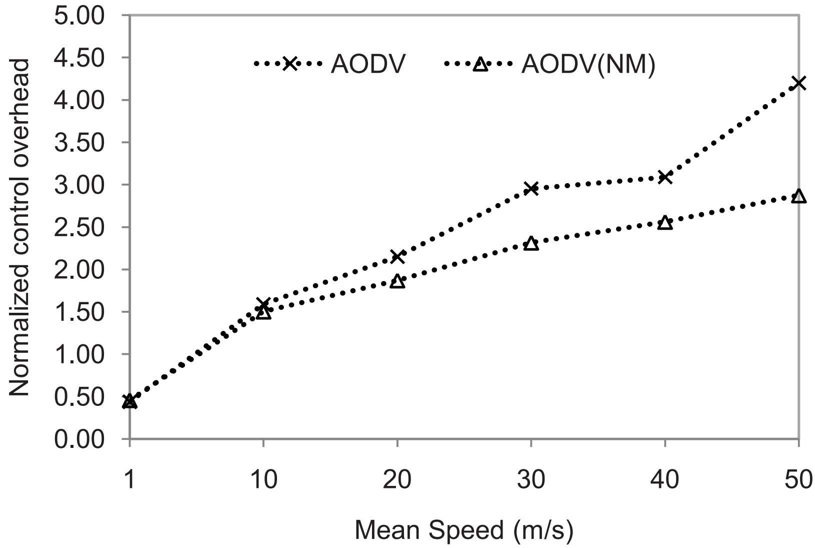

Fig. 7. Normalized routing overhead vs. Mobility

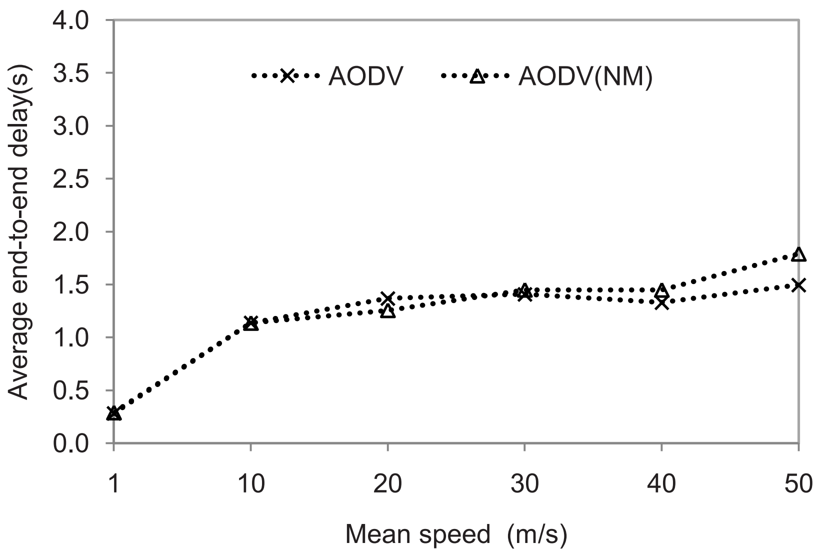

Fig. 8. Average end-to-end delay per packet vs. Mobility

End-to-end delay of packet transmission depends on the number of hops between the source and the destination, and the duration elapsed in route formation. As mentioned earlier in this section, the number of hops between the source and the destination are more in AODV(NM). It is therefore expected that end-to-end delay will be more in AODV(NM). However, there are many factors that compensate for this delay in AODV(NM). These factors are less frequent route breakage, lower broadcast overhead and faster route selection process due to a smaller number of nodes involved in routing. Therefore, as shown in Fig. 8, as the mean speed of the nodes becomes high such as 40 or 50 m/s, AODV(NM) gives more emphasis on forming a reliable link that can last longer. For that reason, it starts selecting nodes that are closer to R_{min} in the reliable coverage area. Therefore, average distance between nodes in a route decreases. It causes larger number of hops between the source and the destination which nullifies any gains made in terms of lower broadcast overhead and a smaller number of nodes involved in the route formation.

5 Conclusions

Simulation studies show that the introduction of a reliable coverage area based LET metric in route selection in AODV is not only able to ensure long lasting routes, but also able to minimize the number of hops between the source and the destination as much as possible within a specified reliable coverage area. Thus, though, the number of hops in AODV (NM) is slightly higher than for traditional AODV, yet it has a comparable average end-to-end delay performance with respect to traditional AODV. It is due to the fact that the AODV(NM) has lower broadcast overhead due to lower number of nodes involved in route formation. Simulation results also show that AODV(NM) behaves quite similar to traditional AODV at a low relative speed of mobile nodes. This shows that the introduction of a reliable coverage area based LET concept did not deteriorate any of the basic performance metrics of the traditional AODV protocol, at least at a low relative speed of mobile nodes. However, the advantage of using links within a reliable coverage area in route formation becomes more and more visible with the increase in relative speeds of mobile nodes due to formation of stable and reliable routes in AODV(NM).

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