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COMP28411 Computer Networks
Lecture 9

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Multimedia – 2

Some material from:

Kurose & Rose – Chapter 7 + Slides

Halsall – Multimedia Communications

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Multimedia 2 - Summary

- TCP or UDP?
- What is meant by "Best Effort"?
- Real-time constraints.
- Unicast vs. multicast.
- How can multicast be implemented in the Internet?

- Next time:
  - Content Deliver
  - Quality of Service (QoS)
  - Home media delivery.

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Best Effort?

Q

- Internet gives no promises.
- Packets delays due to (a few reasons…):
  - Encoding, packetizing, send queues at source. – **have some influence.**
  - Intermediate Queues, schedule delays at each intermediate router. – **no control of these!**
  - Arrive queue, de-packetizing, de-encoding at destination. – **have some influence.**
- Multi Media is typically **delay sensitive**
  - **end-to-end delay**
  - **delay jitter**
  - **round trip response time**

Why X/16?

Jitter is the variability
Of packet delays within
The same packet stream.
Delay = $RX_{time} - TX_{time}$
$Jitter_n = J(i-1) + (|D(i-1,i)| - J(i-1))/16$

  - **Loss tolerant**: infrequent losses cause minor glitches
  - Opposite of data, which is **loss *intolerant*** but **delay *tolerant***.

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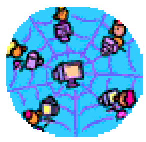
TCP – Issues (Why not use TCP?)

Q



- **Ideal for data for Web, Database, Email, FTP, …!**
- **Connection**: **?**
  - Everything is set up before use, torn down afterwards. **?**
    - Must wait before starting to send data. **X**
  - But – used to maintain state. **+**

- **Byte stream**:
  - Data fragmented into packets not samples. **X**
  - TCP not application decides on packing. **X**
- **In order, error free delivery**: **+**
  - On error – must wait for successful re-transmission – long delay? **X**
  - On loss (dropped) – must wait for successful re-transmission – long delay? **?**
  - Limited number of sequence number bits – not often an issue! **?**
- TCP Congestion Control **X**
  - Traffic delayed, thrown away, slowed down, stopped to control congestion at each router (window size set to zero).

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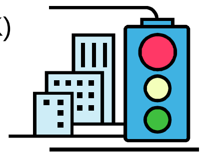
UDP Issues (Why use UDP not TCP?)

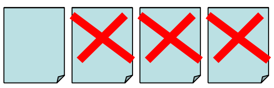
Q

- **No connection**: **?**
  - The application must keep track of who to send to, where it is up to…. **X**
  - Can start straight away, stop straight away. **+**
- **Packet Stream**: **?**
  - But packets contain bytes?
    - Yes but application can decide how many samples to put into each packet. **+**
      - Keep small to avoid fragmentation limits.
- **Any order delivery, with errors ?**
  - On error – may not care? Could throw data away, use some, replace with prediction/previous/next (if available). **+**
  - On dropped - play silence / previous / prediction / next frame. **?**
- Could invent another transport protocol better for multi-media. **?**
  - Must run alongside TCP + UDP and not interfere!
- Could start with UDP and add further features to support multi-media e.g. RTP.

What to Do If a Packet Fails to Arrive OR Arrives but has Errors?



- **Wait** (implies do not send an Acknowledgment (ACK))
  - Maybe the missing packet is re-transmitted (TCP).
- If expected, **send a NACK**. (used in Bluetooth)
  - Should cause a re-transmission
- It might just have been **late**.
  - May get several copies.



    - Throw away duplicates
    - Use duplicate for error recovery – multiple copies may have different errors?
- **Retransmission delay** can be very high!
  - Media arrives too late to play.
    - Might as well have been un-delivered.

- **Detect errors** with CRC, not always used in UDP (optional)!
  - Data networks usually reject any CRC failed packets
  - Media networks might use these packets if allowed!

CRC at transport layer is end-2-end. Ethernet is data-link layer so point-2-point.

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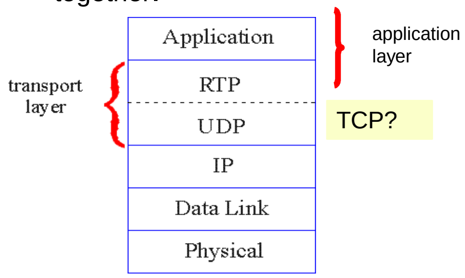
Real-Time Transport Protocol (RTP)

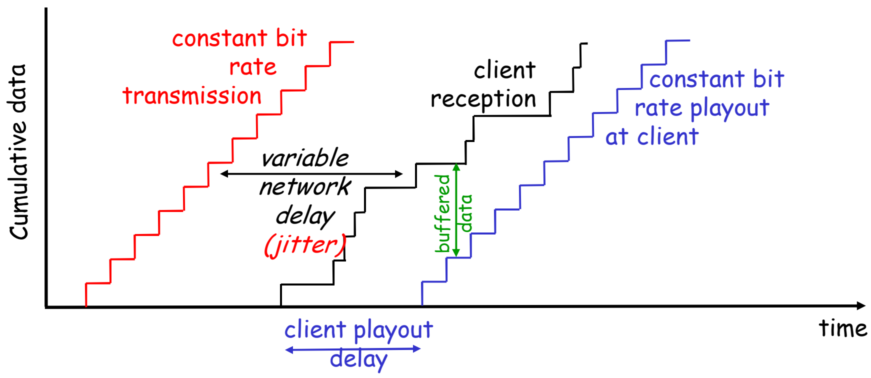
Q

- **RTP** specifies packet structure for packets carrying audio, video data +
- RFC 3550
- **RTP** packet provides
  - Payload type identification e.g. MP3, PCM, …. +
  - Packet sequence numbering – so can re-order at receiver. +
  - Time stamping – so get playback timing right. +

  discussed later
- **RTP** runs in end systems
  - Application Layer but transport oriented. **?**
- **RTP** packets normally encapsulated in UDP segments. **?**
- Interoperability: If two Internet phone applications run RTP, then they may be able to work together. +



Delay Jitter



- Consider end-to-end delays of two consecutive packets: difference can be **more** or **less** than 20 msec (transmission time difference)

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Some Media Examples

- Here is a recording of G711 (see next slide).
- 1st recording. PSTN quality.
  - Now with 50-130ms uniformly distributed sound data with 10% loss.
  - 20% loss.
  - 50% loss.
- Causes of Loss:
  - Late arrival. Beyond jitter buffer delay length.
  - Packet dropped on-route. Congestion?
  - Processing too slow somewhere.
    - CPU speed
    - Machine doing too much.

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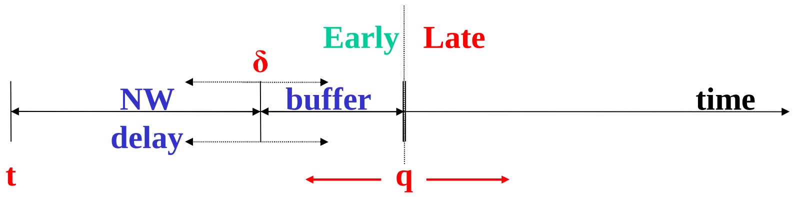
Internet Phone: Fixed Play out Delay

- Receiver attempts to play out each chunk exactly **q** msec after chunk was generated. δ = Jitter
  - Chunk has time stamp **t**: Play out chunk at **t + q** .



  - If chunk arrives **before t + q**: data arrives early for play out, OK provided buffer is large enough..

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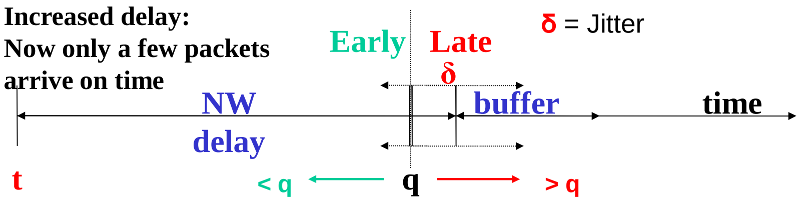
Internet Phone: Fixed Play out Delay

- Receiver attempts to play out each chunk exactly **q** msec after chunk was generated.
  - Chunk has time stamp **t**: Play out chunk at **t + q** .



  - If chunk arrives **after t + q**: data arrives too late for play out, **data is "lost"!** *May be concealed?*
- Tradeoff in choosing **q**:
  - *Large q:* Less packet loss.
  - *Small q:* Better interactive experience.

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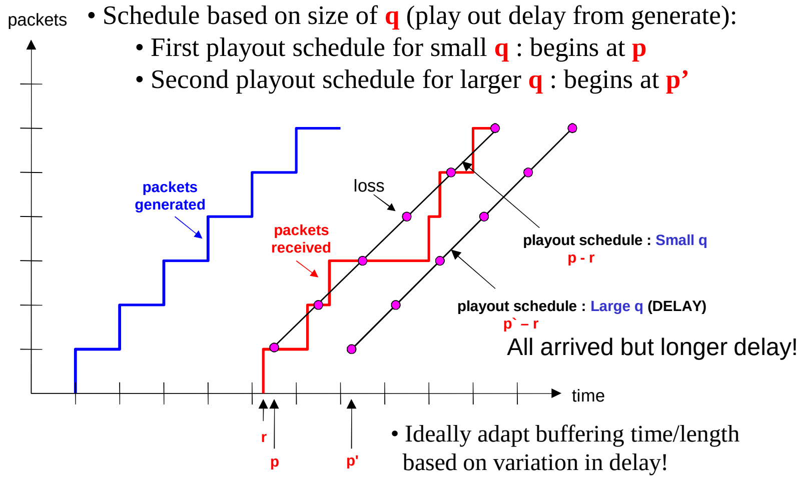
A2

Fixed Play-out Delay

- Sender generates packets every 20 msec during talk spurt.
- First packet received at time **r**
- Schedule based on size of **q** (play out delay from generate):
  - First playout schedule for small **q** : begins at **p**
  - Second playout schedule for larger **q** : begins at **p'**



- Ideally adapt buffering time/length based on variation in delay!

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Adaptive Play-out Delay (1)

A1

- Goal: Minimize playout delay, keeping late loss rate low
- Approach: Adaptive playout delay adjustment:
  - Estimate network delay, adjust playout delay at beginning of each talk spurt.
  - Silent periods compressed and elongated.
  - Chunks still played out every 20 msec during talk spurt.

t_i = timestamp of the ith packet

r_i = the time packet i is received by receiver

p_i = the time packet i is played at receiver

$r_i - t_i$ = network delay for ith packet

d_i = estimate of average network delay after receiving ith packet

Dynamic (moving) estimate of average delay at receiver:

99% $$d_i = (1-u)d_{i-1} + u(r_i - t_i)$$ 1%

Where u is a fixed constant (e.g., u = .01).

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Adaptive play-out delay (2)

- Also useful to estimate average deviation of delay, v_i:

$$v_i = (1-u)v_{i-1} + u\,|r_i - t_i - d_i|$$

99% 1% NW delay – est. NW delay

- Estimates d_i , v_i calculated for every received packet (but used only at start of talk spurt
- For first packet in talk spurt, playout time is:

$$p_i = t_i + d_i + Kv_i$$ Timestamp + est. delay + scaled deviation

where K is positive constant

- Remaining packets in talk spurt are played out periodically.
- If a packet is not available ……

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Real-time Services Wanted?

Q

- What does the internet need to do so (sometimes real-time) multimedia distribution works perfectly?
- Start with TCP + UDP + Best Effort.

- Remember that many streaming services like uTube use TCP and it works very well for them.
  - But it is not perfect!
    - Movies hang in the middle, while the player recovers from a long delay or break in connectivity.
    - Best to download first.
    - Issues with “Jumping Forward”?
    - But ……

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Some Live Media Requirements

- Easy to distribute to one or many destinations.
- Quick start/stop.
- Predictable short delays.
- Low error rate (note: not zero).

- Need to know:
  - Order of events/frames/samples.
  - Event/frame/sample timing.
  - What has arrived and not arrived.
  - What the content is.
  - When/how it synchronizes with other streams of events/frames/samples.

Note

Forward jumping is impossible for live media. Backwards jumping or time shifting can be done via cache and re-play. If multicast is used, lost packets must be very small as usually cannot request re-transmission.

Later streaming may use different methods e.g. download all before or while watching to allow back and forward jumps. For streaming, one or many (unicast) TCP streams are often used. Therefore, no lost packets, but sometimes have to wait due to congestion.

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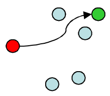
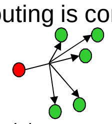
From Unicast to Broadcast



- Unicast
  - Packet sent from one host to one destination.
    - TCP does this, nothing else (why?)! UDP normally does this.
    - Most routing is configured for unicast.



- Broadcast
  - Packet sent to everybody on IPv4, Ethernet etc. but not IPv6!
  - Address is the OR of IP subnet address and bitwise complement of netmask. 192.168.1.0/24 ➔ 192.168.254.255. The address 255.255.255.255 is the broadcast address for the 0.0.0.0 network = This Network.
  - Ethernet (other IEEE 802.x networks – WiFi is 802.11) uses the address FF:FF:FF:FF:FF:FF. IP broadcasts normally sent to this link-layer MAC address.
  - Broadcasts normally blocked at router = boundary.

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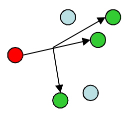
Multicast –To a Group of Destinations



- Source sends one packet, duplicates delivered to many.
- Main multicast protocol is UDP.
  - IPv4 multicast addresses all start 1110 (originally classful – class D). In CIDR it is 224.0.0.0/4 (top address is 239.255.255.255).
    - There are well known (do not use yourself) addresses, e.g. OSPF 224.0.0.5 & 6, RIP 224.0.0.9 and (Internet group Management Protocol) IGMP 224.0.0.22. These 224.0.0.0/24 addresses are IANA assigned and are not forwarded outside local sub-networks by routers.
    - There are various groups of multicast addresses, some are globally assigned and routed, others are available for applications. In IPv6 multicast starts FFxs::/16 where x is a 4 bit flag (bits 8-11) and s is a 4 bit scope (12-15) in the address.
    - Flags: Reserved, Rendezvous (distribution point), Address prefix and Dynamic
    - Some groups/scopes are:
      - Interface-local (≡127.0.0.1), link-local (≡224.0.0.0/24), IPv4 local scope (≡239.255.0.0/16), admin local, site local, organisation local and global.

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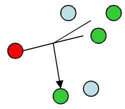
Anycast



- One source talks to an advertised service hosted on multiple servers with the same IP address.
- Normally, layer 3 routing chooses the "nearest" target based on topology.
- Used for:
  - Reliability.
  - Load balancing & performance.
  - Attack resilience.
  - Simplified client configuration.

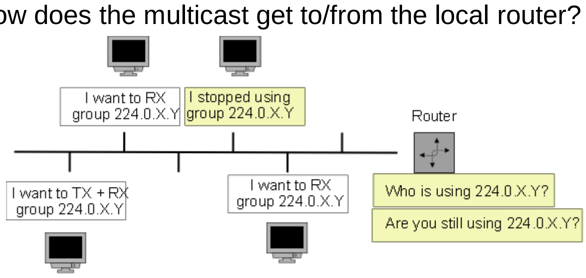
Who do you think uses "anycast"? Lets guess.

- How?
  - Change the DNS resolver. Instead of having a list & timeout between resolver options in list order. Have a group of servers sharing 1 IP address.
  - Get the routers to return the "closest" route to the "anycast" IP.

IGMP Multicast Operation

Internet **G**roup **M**anagement **P**rotocol

- Destination nodes (the network card) report multicast addresses they wish to receive/send traffic from/to.
- A multicast router on a subnet that has the lowest address handles reports and sends queries to maintain its group membership data. In v2, there is also a leave group message.
- So now the local router knows someone wants to use multicast.......
  - How does the multicast get to/from the local router?



TTL Conventions

Pre: 1996 – compare to IPV6 scopes.

0 = localhost

1 = same subnet

< 32 same site

< 64 same region

< 128 same continent

255 Unrestricted

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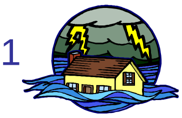
Routing Between Sender and Receivers - 1

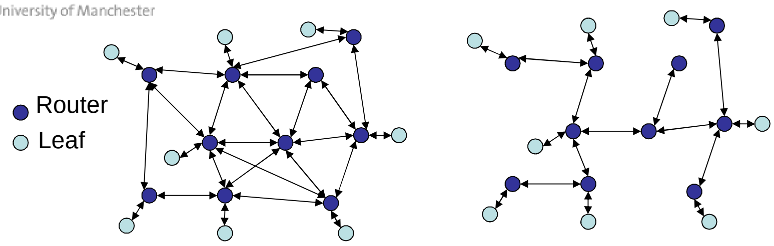


- Sender – Anywhere on the Internet
- Receivers – Can be anywhere
  - Both sender and receivers register with local routers using IGMP
  - How do they find one-another?
- Simplest and least efficient is FLOODING:
  - From source node(s) tell all neighbours, forward to all there neighbours until all connected nodes in tree/graph have received the search discarding repetitions).
    - Simple – no routing table needed – just record of recently seen addresses – but even this may be large!
    - Scaling issue – lots of duplication.

Example: Digital Living Network Alliance (DLNA) for sharing of digital media between devices <phone, computer, TV, Camera> uses multicast and Universal Plug and Play (UPnP) for discovery + control.

Spanning Tree

P



- Select a sub-set of connected nodes – spanning tree.
- Multicast router forwards packets to all nodes that are part of the spanning tree (not the one it arrived on!).
  - No loops
  - Still reaches all the tree eventually.
  - Lots of good algorithms to find (*minimum*) spanning trees.
  - But, concentrates traffic on a few core routes, not always the best path from source to all members.

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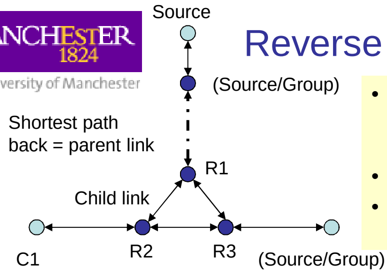
Reverse Path Broadcasting - 1



- Router forwards packet if it arrives on a link the router thinks is shortest path back to (source/group).
- Otherwise discards packet.
- R2 considers R1 as on shortest link back, not R3.

- Group specific spanning tree for each (potential/active?) source. Result is source rooted delivery trees for each source per group.
- Further pruning is if a neighbour router does not consider this router as being on its shortest path back to the source.
  - Easy as all routers have a full topological record.
  - Can either advertise (R1 ➔ R2, R1 ➔ R3), discard (R2 ➔ R3, R3 ➔ R2) or send backwards a “poison reverse” advert to upstream routers (C1☠➔ R2 ☠➔ R1… if no child in group).

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Reverse Path Broadcasting - 2

- Reasonably efficient, quite simple.
- Routers only need relatively local knowledge.
- Packets always follow “shortest” (?) path.
- Packets from different sources in same group follow different trees/paths so lower likelihood of bottleneck.
- However, the forward adverts still happen whether or not the sub-tree has a group member.
  - R2 & C1 are searched before pruning later.

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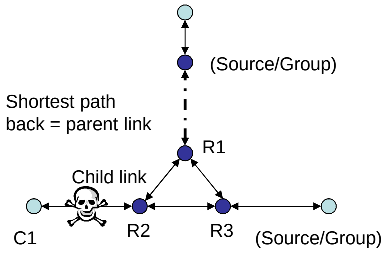
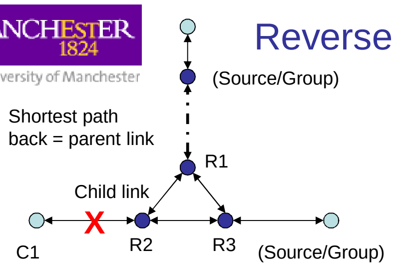
Truncated Reverse Path Broadcasting



- Using IGMP, multicast routers work out the group memberships for leaf networks. So avoid forwarding if no current members of the group.
- The sub-network tree is pruned by the router.
- But only the final router does this removing some traffic on leaf sub-networks. (R2 does this)

Reverse Path Multicasting - 1



- So far, each leaf router (R2 & R3 above) receives the 1st multicast packet in a source/group.
- If there is a group member in any leaf sub-network the leaf router forwards the packet, otherwise it sends back a prune packet (R2 → R1).
- If R1 (n this example) gets prune messages from both R2 and R3 (all downstream interfaces, it can send the prune upstream.
  - Only LIVE tree branches are now used.
  - Prune information must be stored

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Reverse Path Multicasting - 2

- Because both the tree and the source + group memberships change the multicast tree must be **refreshed regularly**. This results in a full flood and prune.
- There are still scaling issues in the flooding and pruning.
- All routers need to keep information for each group and all its sources.
- In practice may need to cache/group before flooding of add & prune messages to reduce control traffic but at the expense of some extra latency.

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Core Based Routing

- A set of static "centres" are identified at different locations in the network. Multicast traffic is duplicated and may be unicast to these centres.
- Branches grow from core routers towards multicast users. Traffic is multicast from core routers to the leaves of the tree.
- This is more scalable.
  - Router only keep group, not source per group, information.
  - Full tree flooding is avoided as "centre" are statically defined and can be unicast to. Multicast is only used in local clusters.
- Issues:
  - Traffic concentration near core routers. Traffic from all sources uses common links towards core routers.
  - Shared links can create sub-optimal routes and therefore delays.

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Summary

- Delivering media is a continually developing solution.
- Demand, location, time of day, density of users all effect choice of method.
- We have:
  - TCP – End-to-end unicast, reliable but subject to delays, duplication, bottlenecks (hot-spots).
  - UDP - End to end unicast, unreliable, less delay problems due to accepting losses. Avoid duplication partially via multicast.
    - Multicast, lots of ideas and protocols. Demand sensitive but more efficient than unicast near tree leaves.
  - Content delivery for news, media etc. Application and usage dependent.
  - P2P using unicast or unicast + multicast great for load spreading.

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Questions

- Most media is stored in the cloud. Why is this often a good idea currently? When is it not that good an idea?
- Why do you think a large amount of jitter is bad for media players?
- Why does'nt uTube use mulitcast?
- Why is multicast little used currently? (not easy to find much on this)
- How does UPnP work? Why is it suited for media handling tasks?
- Is tele-conferencing currently mainly unicast or multicast, P2P or centralized?

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