画像情報特論 (5)
Advanced Image Information (5)

TCP over Wireless

情報理工・情報通信専攻　甲藤二郎

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TCP over Wireless

Wireless issues

- error control (L1)
  - BER (bit error rate), PER (packet error rate)
  - error model: AWGN, Two-States Markov
- access control (L2)
  - CSMA/CA (MACA, MACAW):
    - interference, collision
    - hidden terminal, exposed terminal
    - grey zone: receive range & carrier sense range
  - TDMA, FDMA, CDMA
- ad-hoc routing (L3)
  - DSDV, DSR, AODV, OLSR, TORA, AOMDV, ...
- transport protocol (L4)
  - Wireless TCP/TFRC, multi-hop TCP/TFRC
- mobility management (L3 / L7)
  - Mobile IP (L3), SIP mobility (L7)
- energy consumption (all layers)
  - energy model

Discussion

- Wireless LAN
  - CSMA/CA, half-duplex, interferences, random errors, ...
    - cannot send packets when the sender wants to
    - packets are continuously stored into a transmission buffer of the sender
  - NIC buffer size is very large
    - Hybrid TCP always operates in the loss mode only
  - Unfairness between upload and download
    - D.Leith: WiOpt 2005

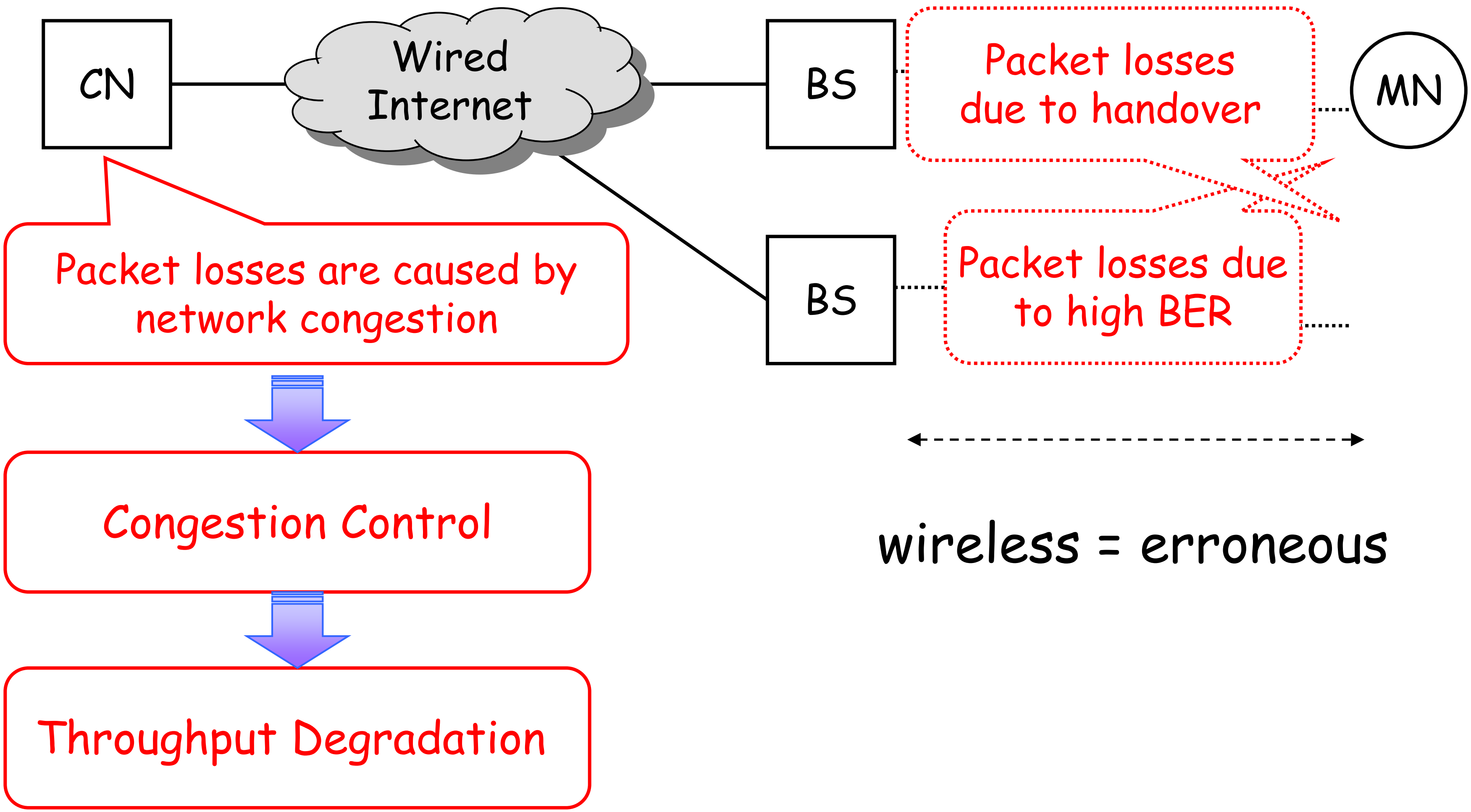
TCP over Wireless
(1) Error Management

Summary

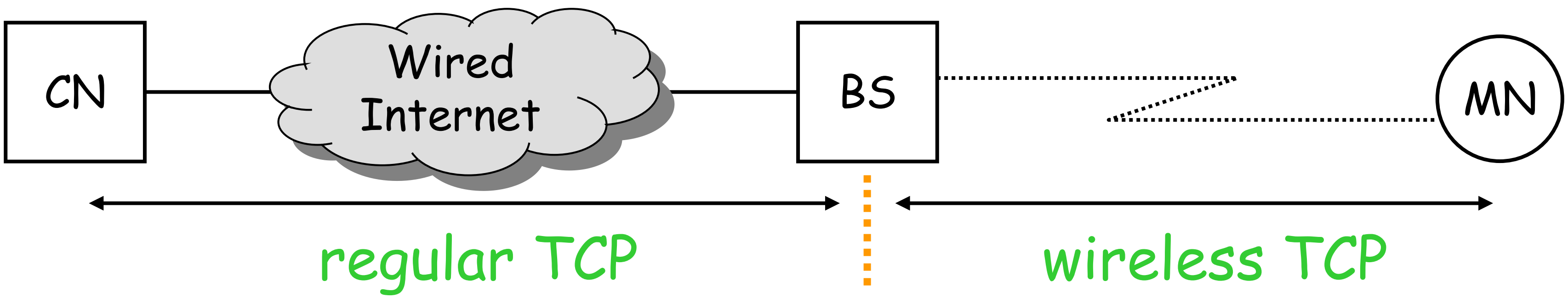
- TCP Extensions for Mobile Networks
  - Split Connection: Indirect TCP
  - Proxy: Snoop TCP
  - End-to-End: Freeze TCP

- L2/L4 collaboration (practical)

TCP over Mobile Networks



(1) Split Connection

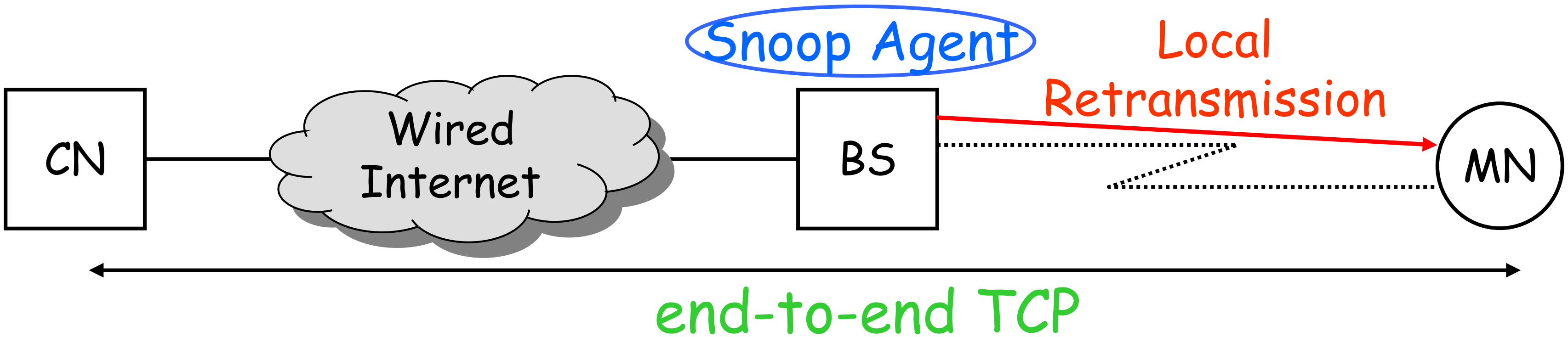


Transmission errors over wireless links are not propagated to wired networks

Forces heavy load on a base station

Breaks end-to-end semantics

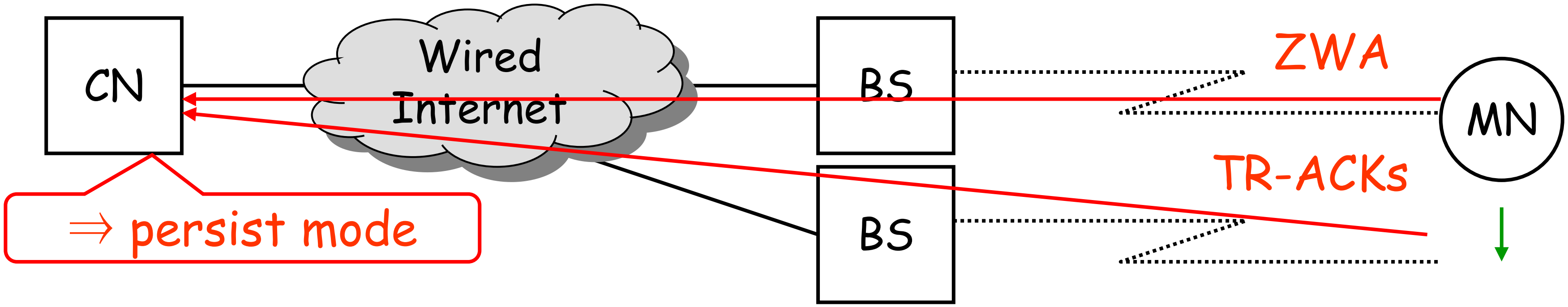
(2) Proxy



Local retransmission over wireless links avoids initiation of unnecessary congestion avoidance

Forces heavy load on a base station

(3) Freeze TCP



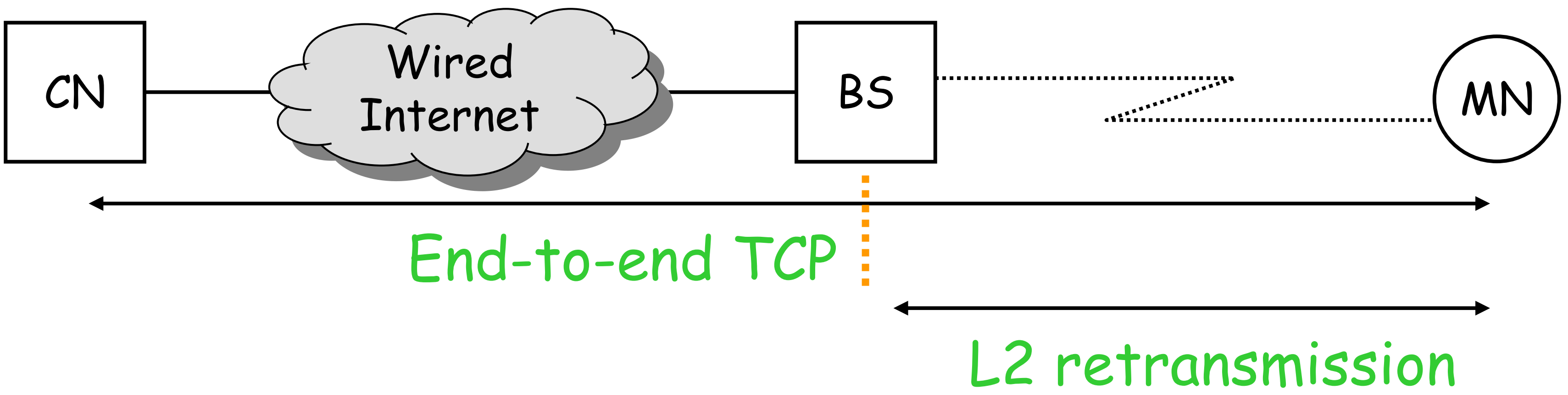
Does not need any base station support

Only TCP of mobile nodes should be modified

A mobile node has to predict a link break precisely before the actual break happens

ZWA: Zero Window Advertisement

(4) L2/L4 Collaboration



Packet losses of wireless links are retransmitted by L2 protocols (e.g. IEEE 802.11, 3G/LTE)

Default retransmission count depends on products: Cisco AP: 32, Buffalo: 4, or adaptive decision

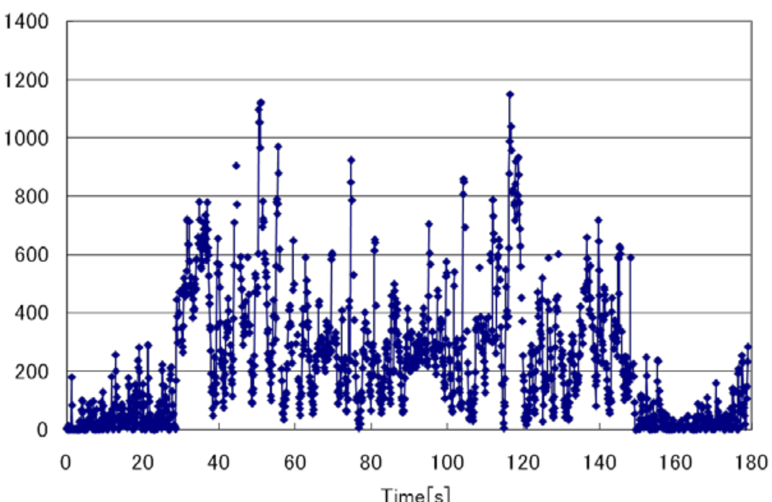
L2 retransmission generally increases latency due to its backoff mechanism

TCP over Wireless Networks (2) TCP Differentiation

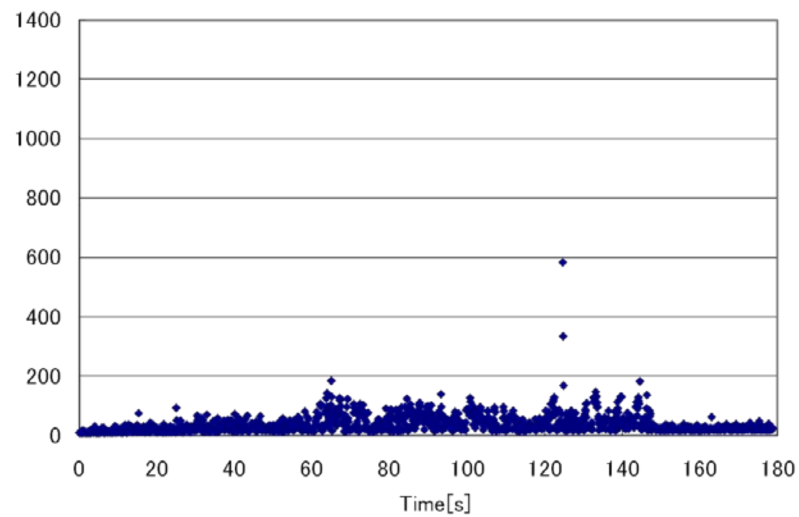
WiFi Example

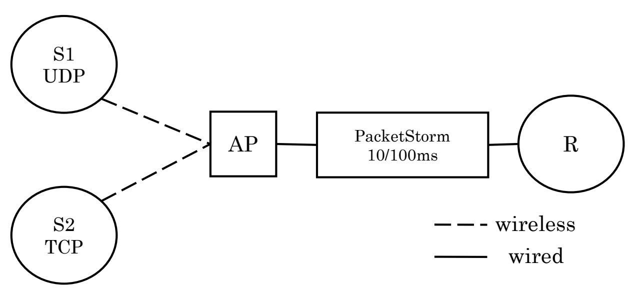
- RTT instability and unfairness between upload and download

RTT upload, wireless to wired



RTT download, wired to wireless



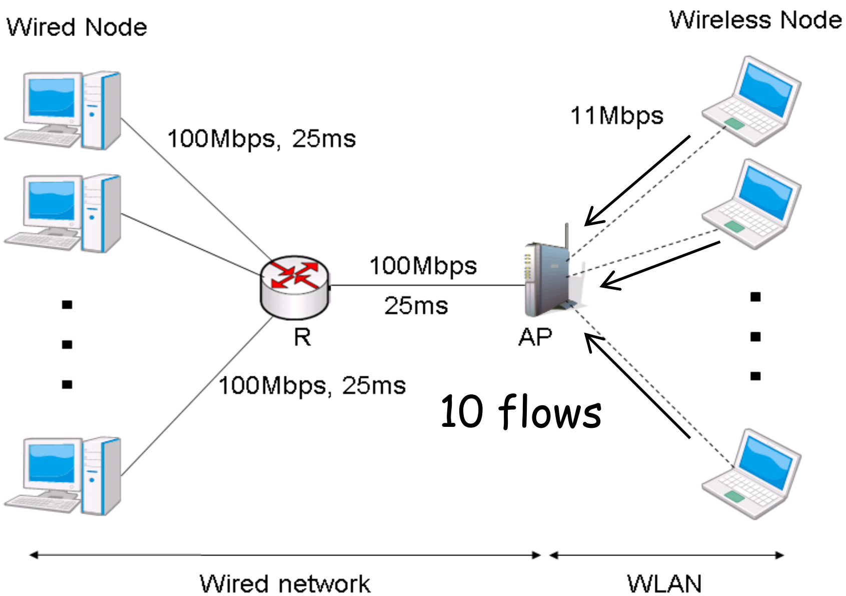


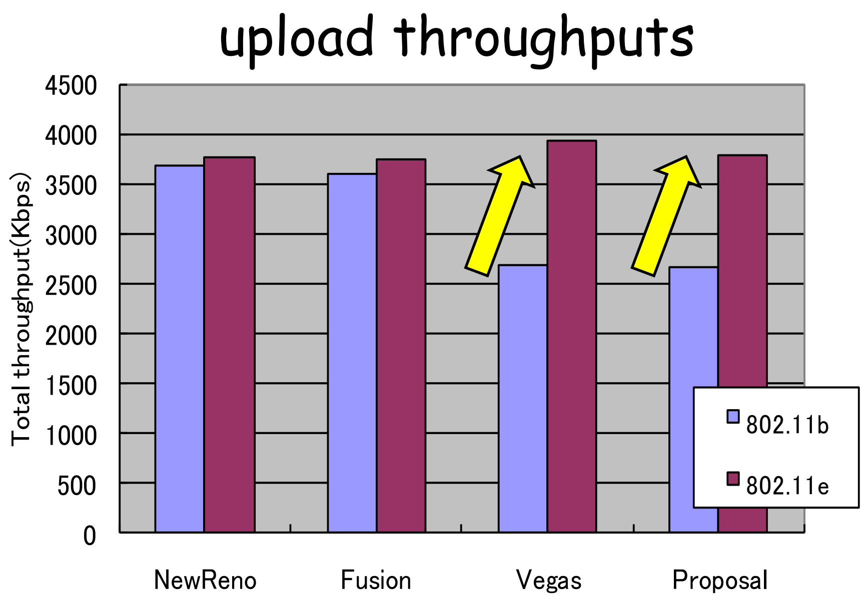
K.Kanai et al: "Performance evaluations of adaptive rate control mechanisms ...", IEICE Tech. Report, 2011.

Wireless LAN (1)

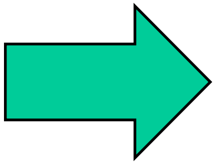
※ ns-2 simulation

- TCPs and throughputs





Apply IEEE 802.11e to alleviate the unfairness problem between upload and download



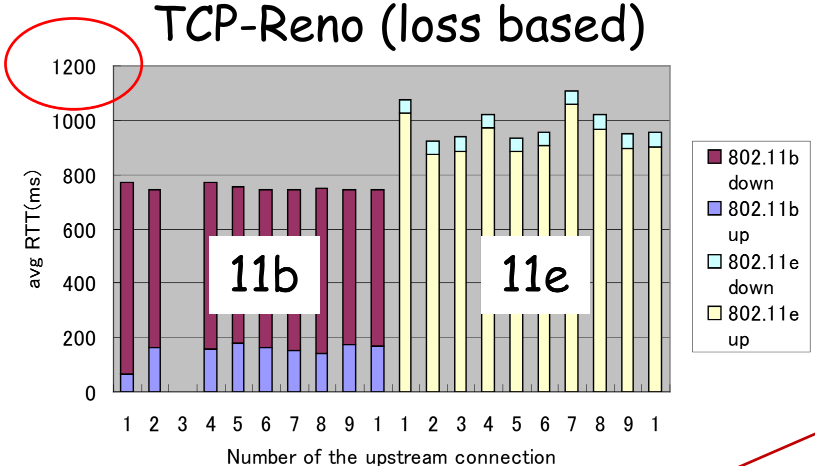
TCP-Reno: loss based
TCP-Fusion: hybrid
TCP-Vegas: delay based
Proposal: Vegas extension

K.Sonoda et al: “TCP Differentiation using Version Identification…”, IEEE CCNC 2013.

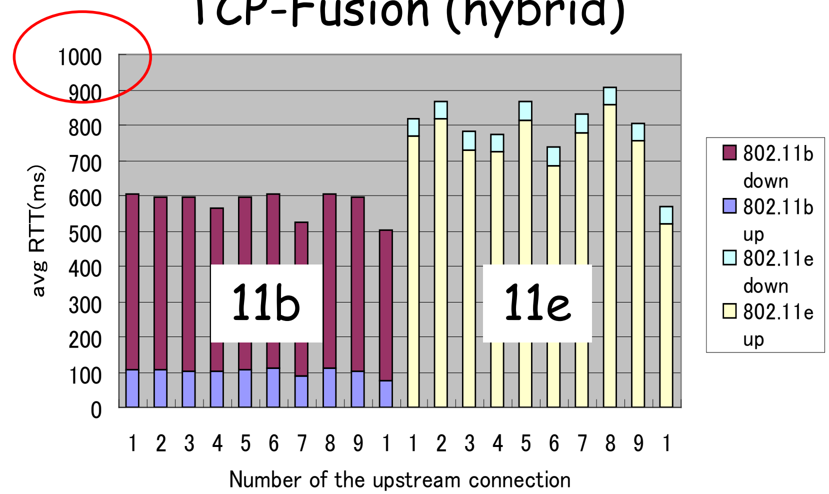
Wireless LAN (2)

- TCPs and delays

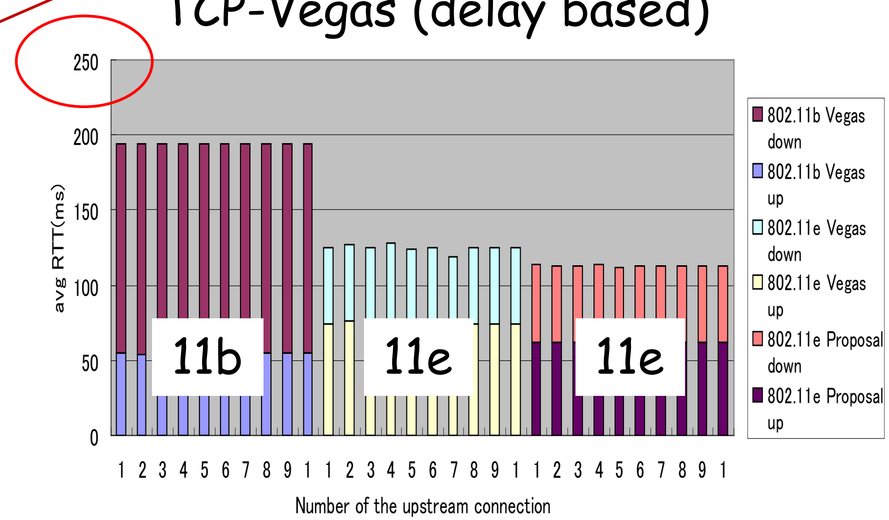
TCP-Reno (loss based)



TCP-Fusion (hybrid)



TCP-Vegas (delay based)



Reno, Fusion: though unfairness was alleviated, delay increases (esp. upload)
Vegas & Proposal: unfairness and delay are decreased (compare vertical axis)

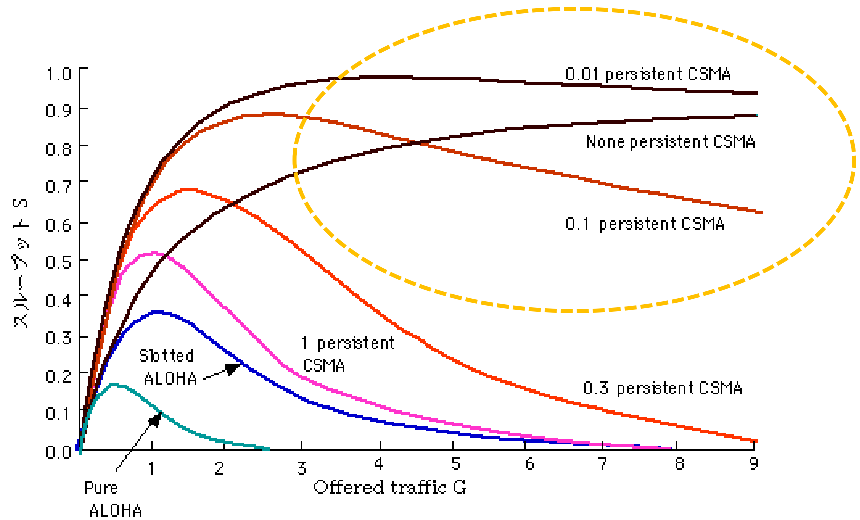
→ Hybrid TCP works in loss mode only

K.Sonoda et al: "TCP Differentiation using Version Identification...", IEEE CCNC 2013.

Wireless LAN (3)

- Common to wired
  - Delay based TCP design is effective if we require low delay transmission (but, it is expelled by loss based flows)
- Differences to wired
  - Hybrid does not operate in "hybrid" (delay mode) due to huge transmission buffer
  - Too many packet insertion causes huge delay due to multiple access mechanism (i.e. CSMA)

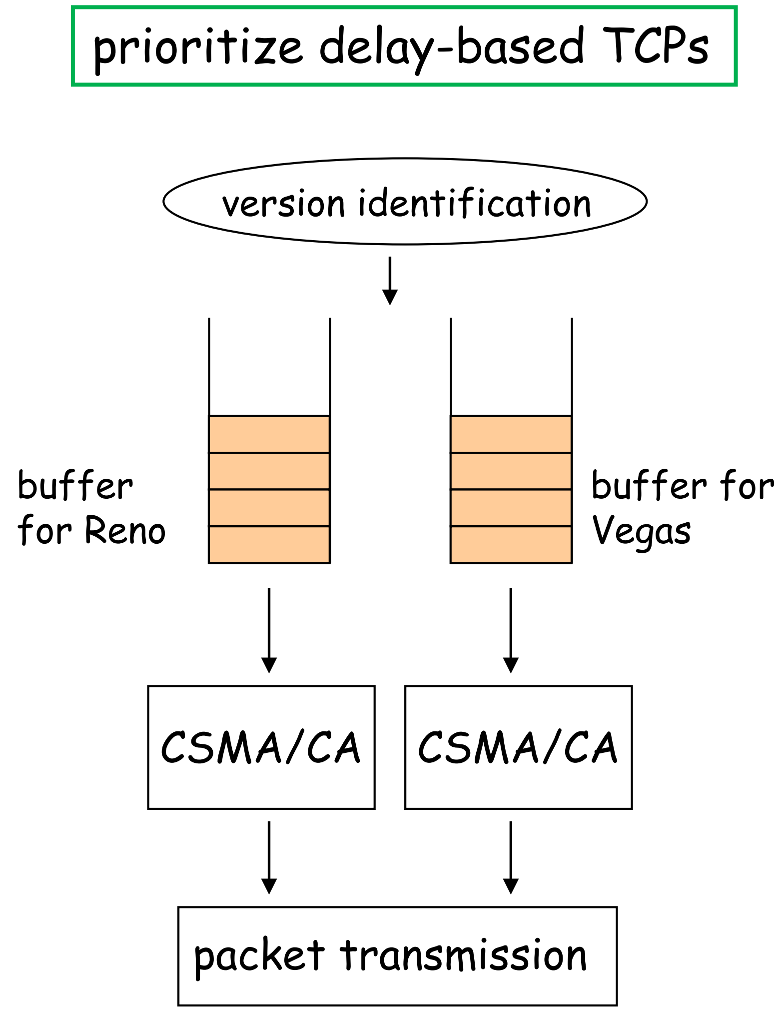
Critical throughput-delay tradeoff due to CSMA/CA



TCP Version Differentiation (1)

TCP version identification and differentiation

1. Access points identify TCP versions using RTT/cwnd estimation
2. Access points separate different TCP versions into different buffers
3. Prioritize delay based TCP flows by tuning CSMA/CA parameters of IEEE 802.11e

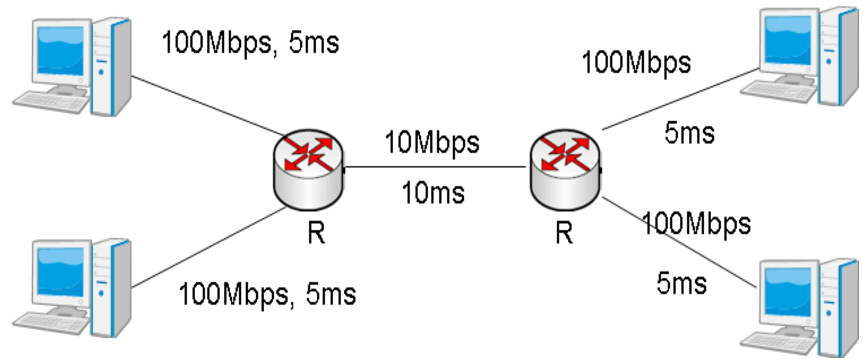


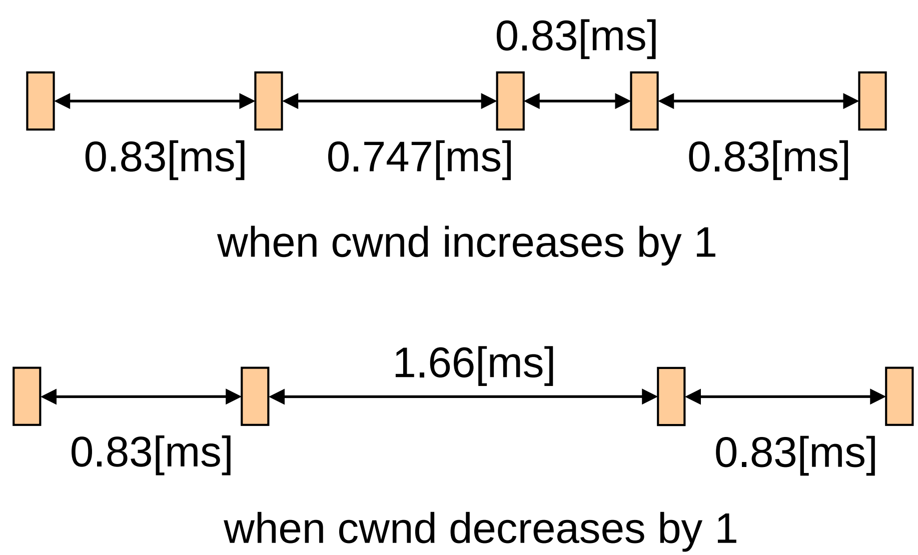
K.Sonoda et al: "TCP Differentiation using Version Identification...", IEEE CCNC 2013.

TCP Version Differentiation (2)

- RTT estimation for delay based flow
  - When cwnd increases by one, two consecutive packets are transmitted
  - When cwnd decreases by one, no packets are transmitted for the last ACK
- cwnd estimation
  - Access points let the number of arrived packets per RTT be "cwnd"

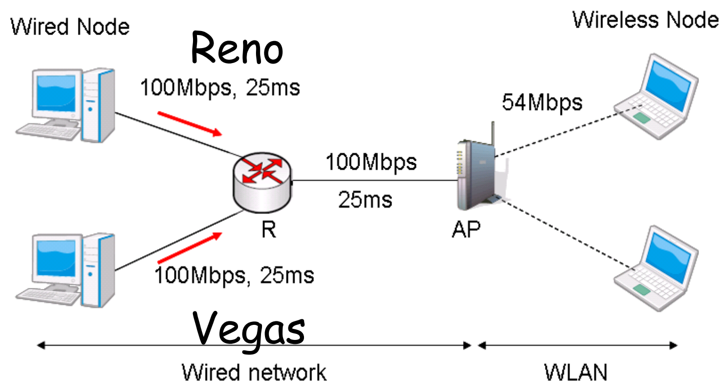
TCP behavior estimation at AP



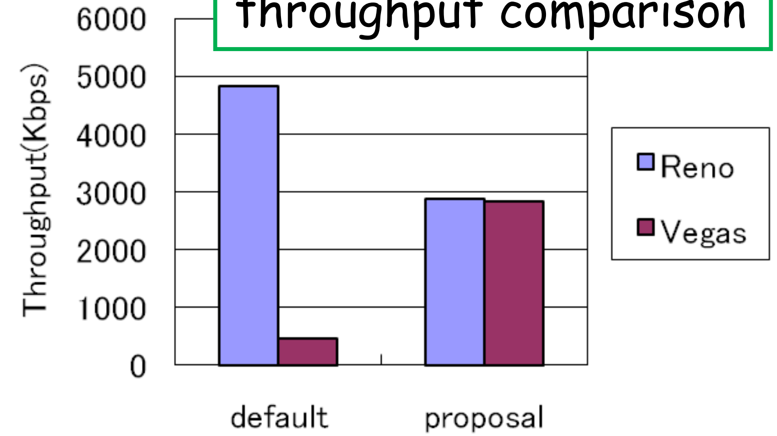


K.Sonoda et al: "TCP Differentiation using Version Identification...", IEEE CCNC 2013.

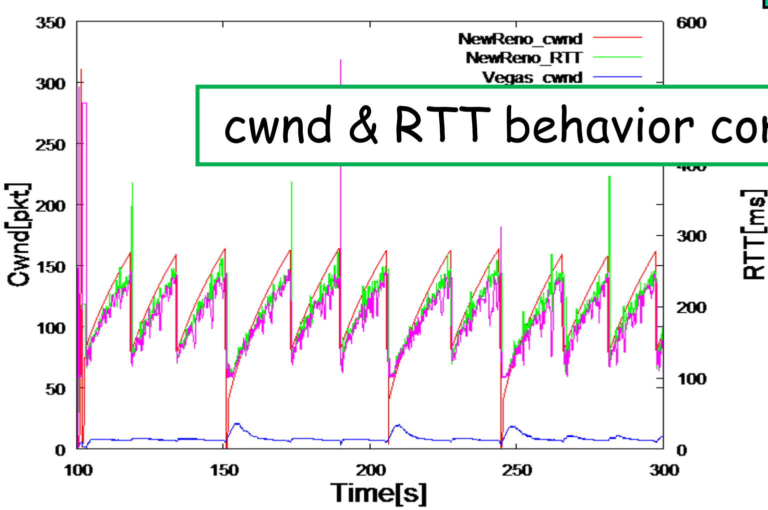
TCP Version Differentiation (3)



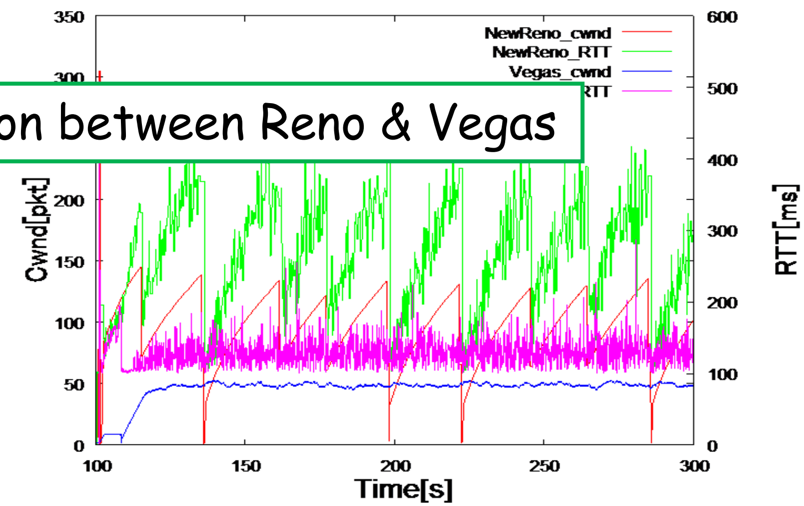
throughput comparison



cwnd & RTT behavior comparison between Reno & Vegas



without differentiation



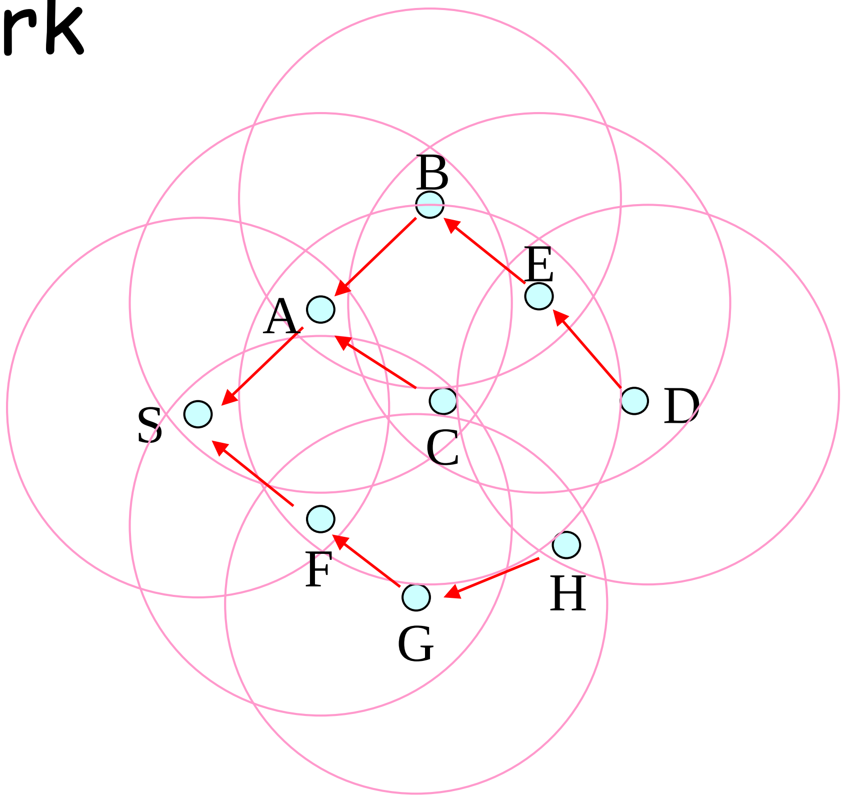
with differentiation

K.Sonoda et al: "TCP Differentiation using Version Identification…", IEEE CCNC 2013.

TCP over Wireless Networks
(3) Multi-hop

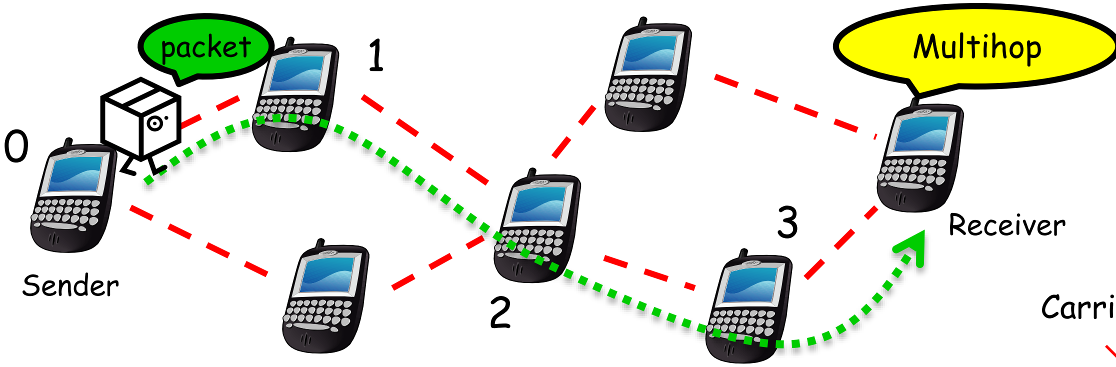
Wireless Multihop Networks

- ad-hoc network
- sensor network

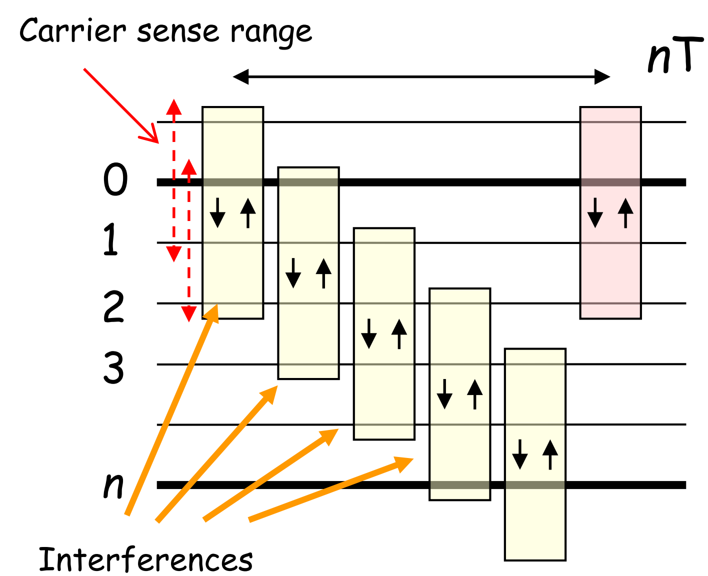


Wireless Multihop Networks (1)

- Single Radio Multi-hop Transmission



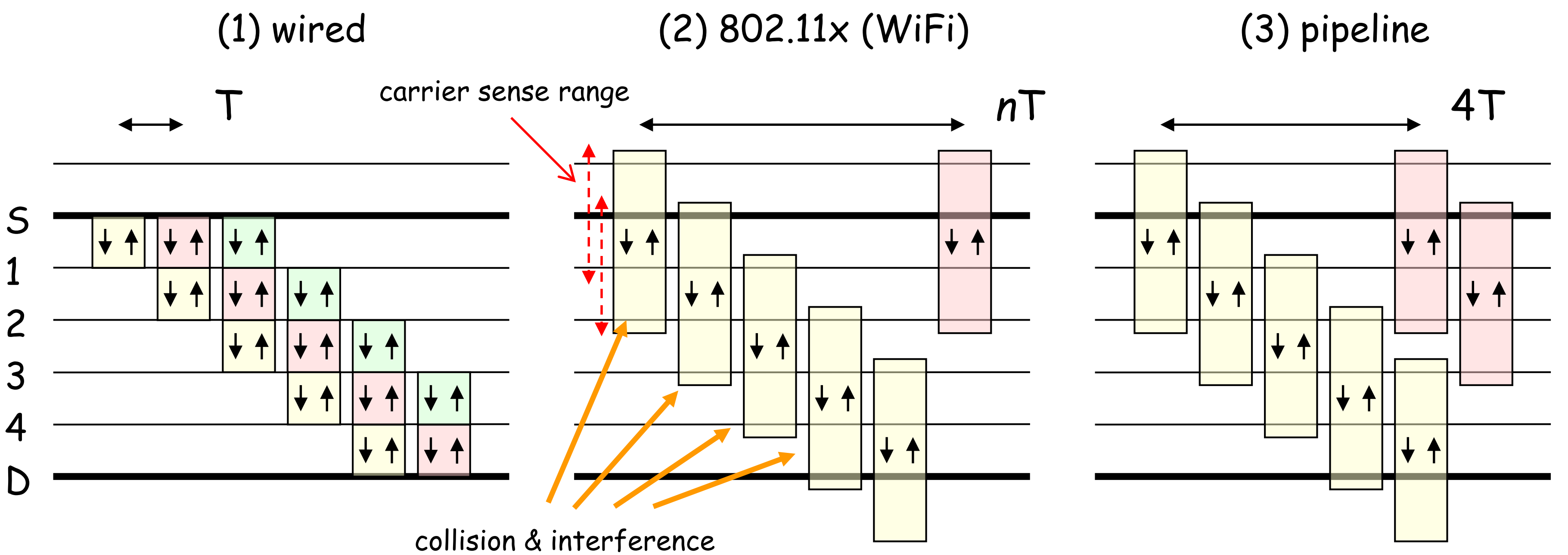
Decrease of link utilization due to radio interferences



Link utilization ratio can be at most 1/4 (or 1/*n* without pipelining, where *n* = # of hops) (J.Li et al.: ACM Mobicom 2001)

Small packet buffering at the intermediate nodes (Z.Hu et al: IEEE INFOCOM 2003)

Multihop Capacity (1)



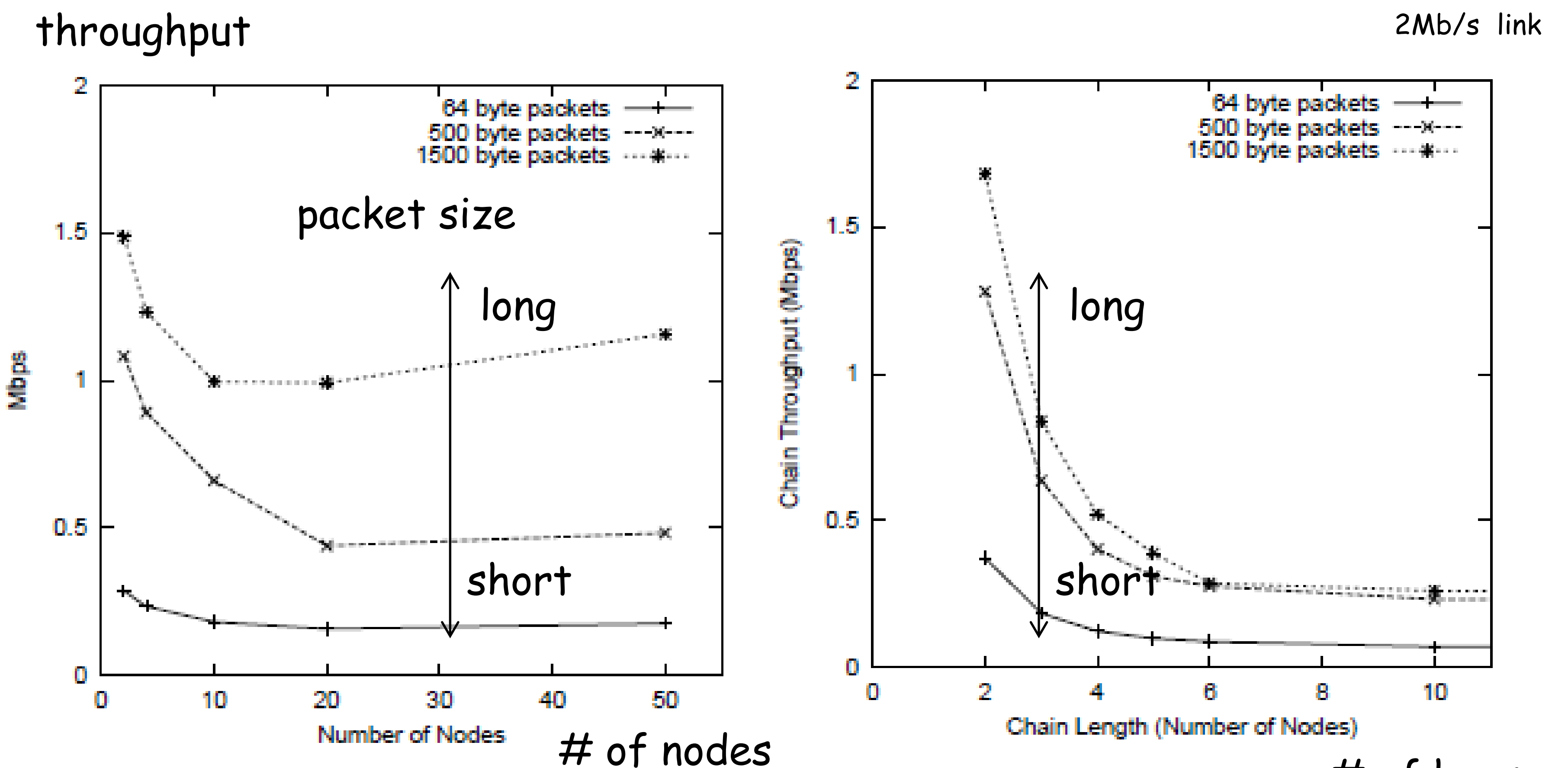
channel efficiency = 1

channel efficiency = $1/n$
(n : hop count)

channel efficiency = 1/4
avoid collision & interference

J.Li et al: "Capacity of Wireless Ad Hoc Networks", ACM Mobicom 2001.

Multihop Capacity (2)



Cell (2D)

Chain (1D)

J.Li et al: “Capacity of Wireless Ad Hoc Networks”, ACM Mobicom 2001.

Link RED & Adaptive Pacing

- Wireless capacity is limited by # of hops (1/4 is the theoretical maximum channel efficiency for chain topology)

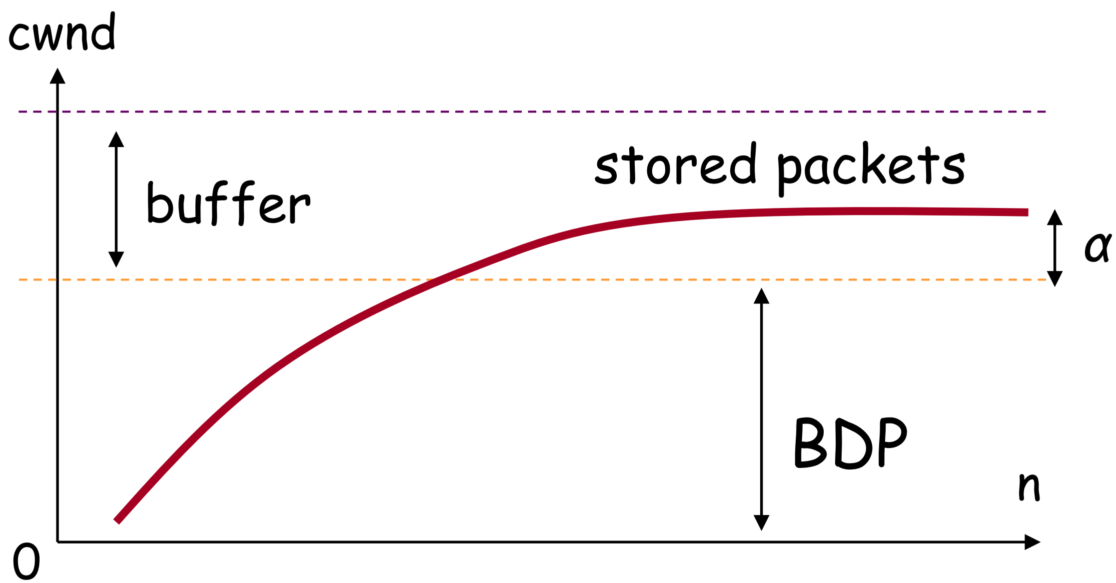
- Distributed Link RED: drops packets randomly at the link level when link load increases (analogous to random early detection)
- Adaptive Pacing: controls packet transmission scheduling in order to approach 1/4 (spatial channel reuse)

	TCP NewReno	LRED+
flow 1	244 Kbps	166 Kbps
flow 2	0 Kbps	153 Kbps
Aggregate	244 Kbps	319 Kbps
Fairness	0.5	0.9983

	TCP NewReno w/standard LL	TCP NewReno w/LL+LRED+PACING
flow 1	532 Kbps	85512 Kbps
flow 2	126229 Kbps	90459 Kbps
flow 3	115554 Kbps	70334 Kbps
flow 4	1608 Kbps	47946 Kbps
Aggregate	242923	294251
Fairness	0.51	0.95

Z.Hu et al: "The Impact of Multihop Wireless Channel on TCP Throughput and Loss", IEEE INFOCOM 2003.

TCP-Vegas (revisited)



e.g. α=1, β=3

$$diff = \left(\frac{cwnd}{RTT_{\min}} - \frac{cwnd}{RTT} \right) \cdot RTT_{\min}$$

stored packets in a buffer

increase: $$cwnd = \begin{cases} cwnd + 1 & diff < \alpha \\ cwnd & otherwise \\ cwnd - 1 & diff > \beta \end{cases}$$

decrease: $$cwnd = cwnd * 0.75$$

Vegas-W (1)

for wireless multihop

- Vegas-W [Ding, C&C 2008]
  - **Slower window increase than TCP-Vegas**

$$cwnd = \begin{cases} cwnd + 1/cwnd & (\Delta < \alpha \ \& \ n_{CA} > N_{CA}) \\ cwnd & (\alpha \le \Delta \le \beta \text{ or } \Delta \le \alpha \ \& \ n_{CA} \le N_{CA}) \\ cwnd - 1/cwnd & (\Delta > \beta) \end{cases}$$

n_{CA}: # of consecutive states entering into

$(\alpha \le \Delta \le \beta \text{ or } \Delta \le \alpha \ \& \ n_{CA} \le N_{CA})$

N_{CA}: threshold (e.g. 100)

→ much slower than TCP-Vegas

L.Ding et al.: "Improve throughput of TCP-Vegas in multihop ad hoc networks", Computer Communications, Jun.2008.

Vegas-W (2)

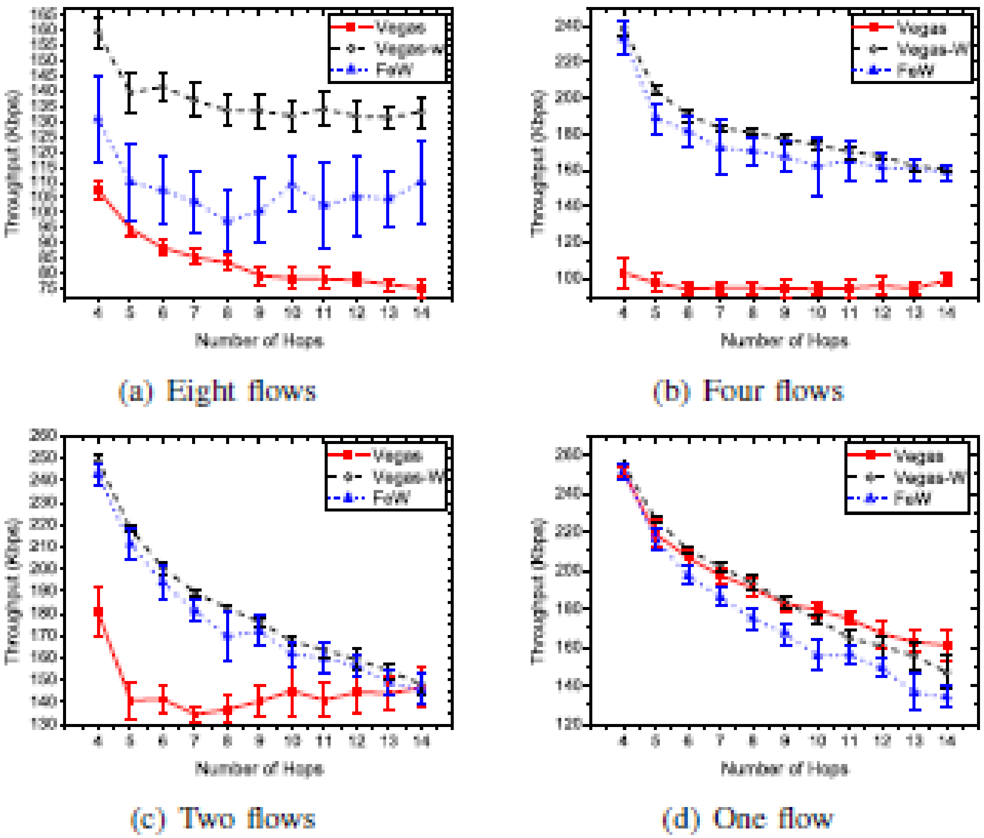


Fig. 4: Throughput comparison over chain topology with DSR and 95% confidence interval.

FeW: Fractional Window Increment (ACM Mobihoc 2005)

Vegas degraded as # of flows increases

Vegas-W improves as # of flows increases

L.Ding et al.: “Improve throughput of TCP-Vegas in multihop ad hoc networks”, Computer Communications, Jun.2008.

Summary of Wireless Multihop Networks

- Common to wired & wireless LAN
  - delay-based TCP is effective as long as no competing loss-based flows exist
- Gap to the wired case
  - wired case: faster window increase "immediately" fills a pipe
  - multi-hop case: slower window increase "safely" fills a pipe

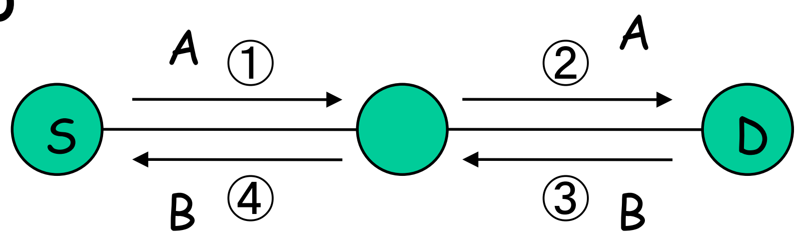
Full-duplex radio

A,B: symbol
a,b: signal

(ref.) Wireless Network Coding

- Multihop

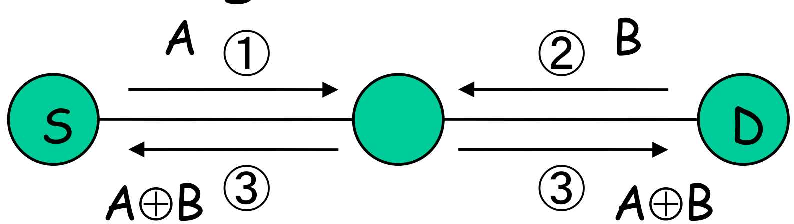
# of time-slots which is necessary to transmit packets A&B between source and destination



4 (channel efficiency1/4)

- Network Coding (in Wireless)

⊕: XOR

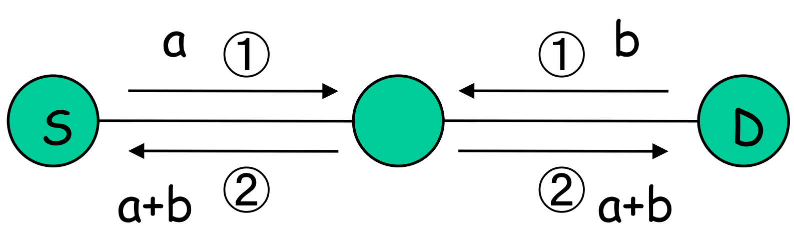


B=A⊕(A⊕B)

A=B⊕(A⊕B)

3 (channel efficiency 1/3)

- Physical-Layer Network Coding



2 (channel efficiency 1/2)

synchronization is the key point

S.Zhang: "Physical-Layer Network Coding", ACM Mobicom 2006.

4K/8K Broadcasting

http://www.soumu.go.jp/main_content/000281299.pdf (2014)
http://www.soumu.go.jp/main_content/000417993.pdf (2016)

Word

- ISDB-S: Integrated Services Digital Broadcasting - Satellite
- DVB: Digital Video Broadcasting
- LDPC: Low Density Parity Check
- MMT: MPEG Media Transport
- HDR: High Dynamic Range
- VoD: Video on Demand

Recent Trends

- Japan
  - 2015: 4K "regular" broadcasting by satellite (CS), CATV and IPTV
  - 2016: 4K/8K "test" broadcasting by satellite (BS/CS)
  - 2018: 4K/8K "regular" broadcasting by satellite (BS/CS)
  - ISDB-S3 (2014): broadcasting standard for UHDTV (4K/8K) by satellite
- Korea:
  - 2015: 4K regular broadcasting by satellite
  - 2018: 8K broadcasting experiment by satellite

Recent Trends

- Europe:
  - 2013～: 4K broadcasting by satellite
  - DVB-S2 (2005): broadcasting standard for 2K/4K by satellite
  - DVB-T2 (2008): broadcasting standard for 2K/4K by terrestrial
  - DVB-S2X (2015): broadcasting standard for UHDTV (4K/8K) by satellite

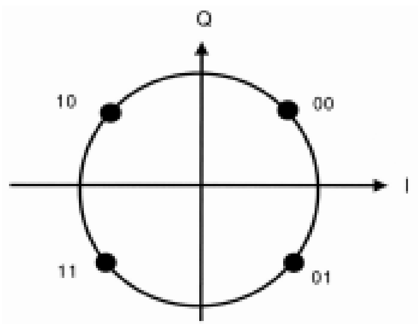
- USA
  - 2014～: 4K VoD service by Netflix, Amazon, and so on
  - ATSC 3.0 (2016): broadcasting standard for 2K/4K by terrestrial and CATV

ISDB-Sx

		BS, 110°CS		
		ISDB-S (1998)	ISDB-S2 (2009)	ISDB-S3 (2014)
Frequency		11.7～12.2GHz（BS）、12.2～12.75GHz（CS）		
Bandwidth		34.5MHz		
Modulation		BPSK/QPSK/8PSK	BPSK/QPSK/8PSK	BPSK/QPSK/8PSK/**16APSK (32APSK)**
Error correction code	inner	Convolutional	**LDPC**	**LDPC**
	outer	RS	BCH	BCH
Data rate		52Mbps (8PSK, 2/3)	70Mbps (8PSK, 3/4)	100Mbps (16APSK, 7/9)
Multiplexing		MPEG-2 TS	MPEG-2 TS	MPEG-2 TS / **MMT**
Video coding		MPEG-2 Video	**H.264/AVC**	**H.265/HEVC**
Audio coding		MPEG-2 AAC	MPEG-2 AAC	MPEG-4 AAC, MPEG-4 ALS
Video format		480/I, 480/P, 720/P, 1080/I	480/I, 480/P, 720/P, 1080/I	1080/I, 1080/P, **2160/P (4K), 4320/P (8K)**
Color		ITU-R BT.709	ITU-R BT.709, xvYCC	ITU-R BT.709, xvYCC, **ITU-R BT.2020**

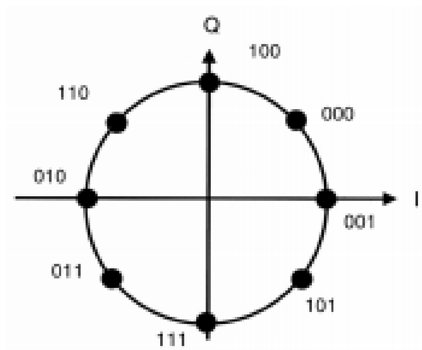
16APSK, 32APSK

QPSK



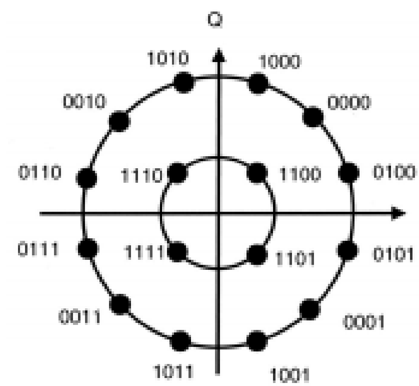
2bit/symbol

8PSK



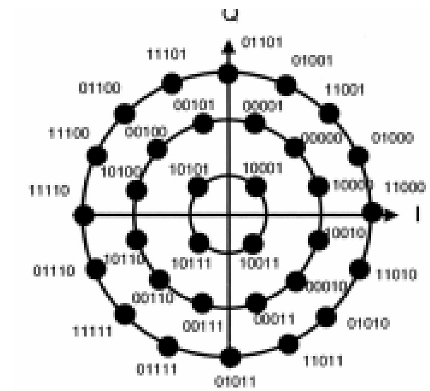
3bit/symbol

16APSK



4bit/symbol

32APSK



5bit/symbol

data rate

low → high

against error

robust ← weak

HDR Extension (2016)

<table>
<tr><th colspan="2"></th><th colspan="2">2K</th><th colspan="2">4K</th><th colspan="2">8K</th></tr>
<tr><th colspan="2"></th><th>1080/60/I</th><th>1080/60/P</th><th>2160/60/P</th><th>2160/120/P</th><th>4320/60/P</th><th>4320/120/P</th></tr>
<tr><td colspan="2">Horizontal</td><td colspan="2">1,920</td><td colspan="2">3,840</td><td colspan="2">7,680</td></tr>
<tr><td colspan="2">Vertical</td><td colspan="2">1,080</td><td colspan="2">2,160</td><td colspan="2">4,320</td></tr>
<tr><td colspan="2">Frame rate [Hz]</td><td>30/1.001, 30</td><td>60/1.001, 60</td><td>60/1.001, 60</td><td>120/1.001, 120</td><td>60/1.001, 60</td><td>120/1.001, 120</td></tr>
<tr><td colspan="2">Scan</td><td>Interlace</td><td colspan="5">Progressive</td></tr>
<tr><td rowspan="2">SDR-TV</td><td>bit</td><td colspan="2">8-bit, 10-bit</td><td colspan="4">10-bit</td></tr>
<tr><td>color</td><td colspan="2">ITU-R BT.709,
IEC 61966-2-4 (xvYCC),
ITU-R BT.2020</td><td colspan="4">ITU-R BT.2020</td></tr>
<tr><td rowspan="3">HDR-TV</td><td>bit</td><td colspan="6">10-bit</td></tr>
<tr><td>color</td><td colspan="6">ITU-R BT.2020</td></tr>
<tr><td>Transfer function</td><td colspan="6">HLG (Hybrid Log-Gamma) NHK/BBC
PQ (Perceptual Quantization) Dolby</td></tr>
</table>

BT.2020 and BT.2100

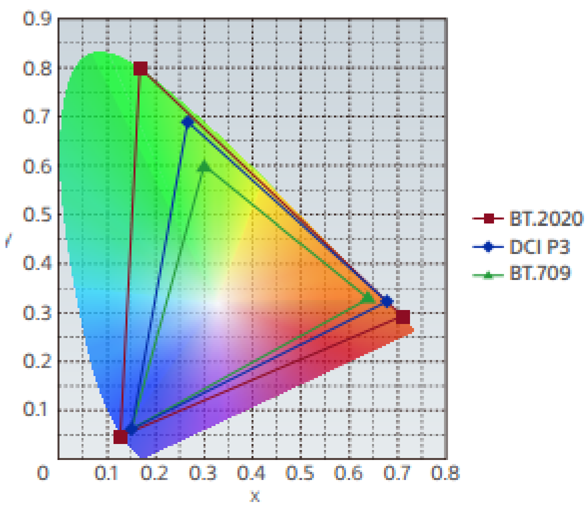
ITU-R BT.2020 defines
- resolutions (4K/8K)
- frame rates (up to 120P)
- bit depth (10/12 bits)
- wider color space

for UHDTV

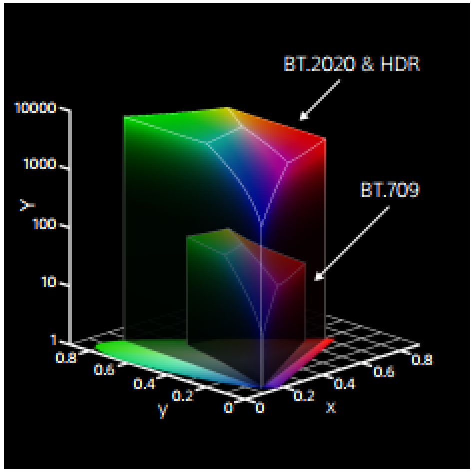
ITU-R BT.2100 defines
- resolutions (2K/4K/8K)
- frame rates (up to 120P)
- bit depth (10/12 bits)
- optical transfer function

for HDR video

Wider Color Gamut

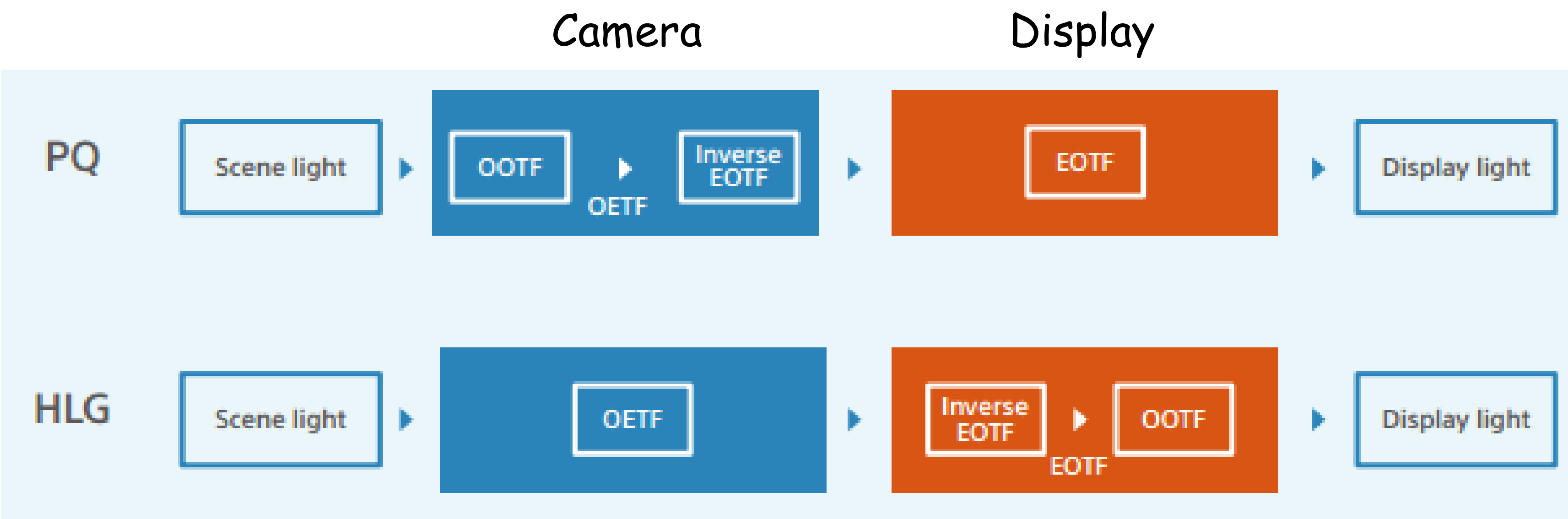


Color Volume



https://assets.pro.sony.eu/Web/commons/solutions/pdfs/HDR_Explained.pdf

Transfer Function



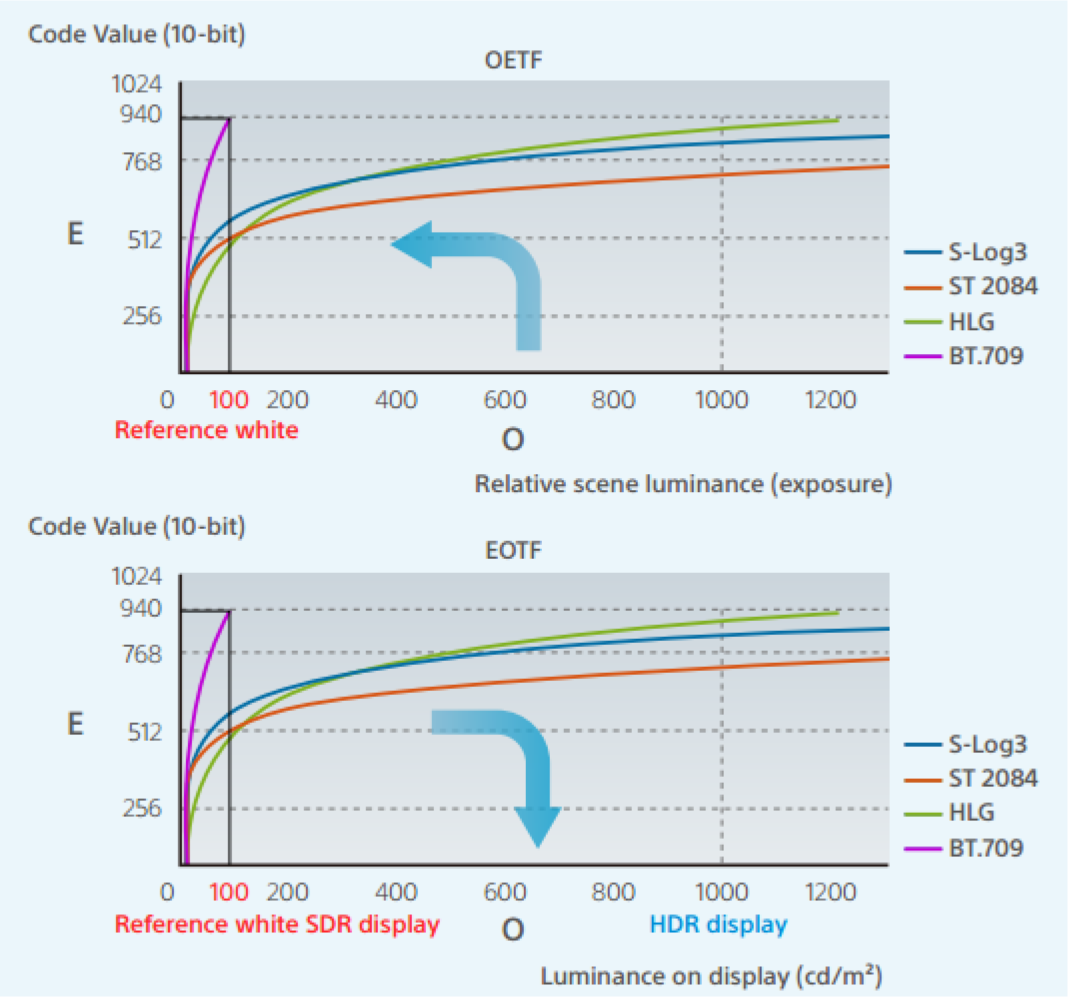
OETF: opto-electronic transfer function
EOTF: electro-optical transfer function

inverse

OOTF: opto-optical transfer function, which adjust the final look of display images

https://assets.pro.sony.eu/Web/commons/solutions/pdfs/HDR_Explained.pdf

Transfer Function



ST.2084 = PQ

https://assets.pro.sony.eu/Web/commons/solutions/pdfs/HDR_Explained.pdf