Connectivity with Multihop Relaying for WiFi-based Vehicular Internet Access

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Vehicular Internet Access

- Increasing need for staying connected on the move as people spending more time travelling
- Many varied applications [Gerla et al, WICON'06]:
  - Web browsing, e-mail, messaging, p2p
  - Multimedia apps: stored audio/video streaming, live streaming (e.g., IPTV), interactive (e.g., VoIP)
  - Road traffic management and safety, location-aware apps, …
- Cellular-based access: nearly ubiquitous, but poor price/performance ratio
  - Low and variable data rates (esp. at driving speeds) and occasional communication blackouts [Qureshi & Guttag, MobiSys'05]
    - Can alleviate the above via aggregating multiple cellular channels and exploiting diversity, e.g., MAR (mobile access router) [Rodriguez et al, MobiSys'04] and on-board WiFi service on GNER trains
  - Costly (e.g., $60/mo. service with Verizon in US for ~200Kbps download speeds)

WiFi-based Vehicular Internet Access

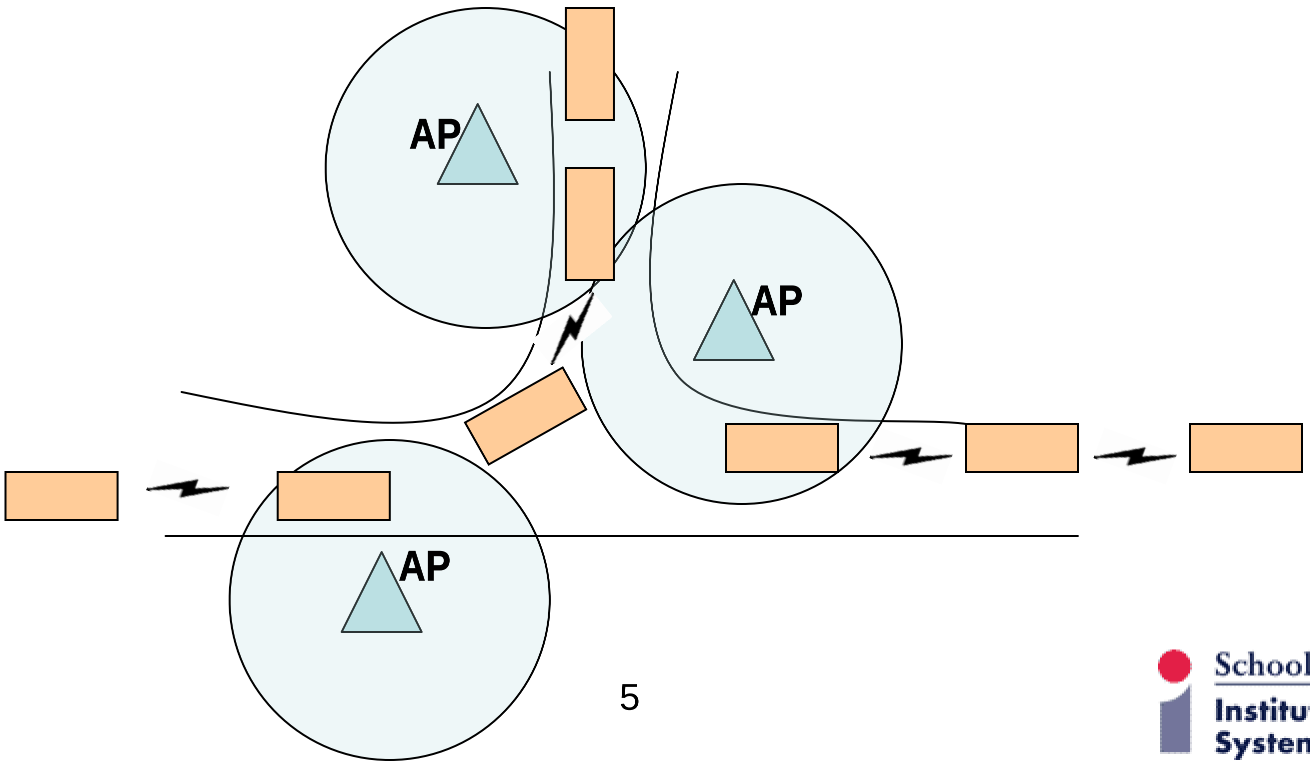
- Widespread deployment of WiFi (802.11) access points (APs) esp. in urban and sub-urban areas
  - Hotspots, homes, community/municipal mesh networks, university campuses, enterprises, …
- Higher data rate compared to cellular at least by an order of magnitude (up to 54Mbps) and potentially free
- But medium range (several tens to few hundreds of meters)
- **Key challenge:** ensuring continuous and seamless connectivity in dynamic vehicular environments

WiFi-based Vehicular Internet Access (2)

- Internet connectivity depends on several factors:
  - AP density and distribution
  - Vehicle density, distribution and speed
  - Communication range of nodes (APs and vehicles)
    - dependent on radio hardware, regulations and parameter settings (e.g., transmit power, rate)
- Recent measurement studies [Balakrishnan et al, Mobicom'06; Diot et al, WMCSA'06; Ott & Kutscher, Infocom'04]
  - Show feasibility of WiFi-based vehicular Internet access
  - Observed short connection durations (few tens of seconds), so suggest such access only useful for applications tolerating intermittent connectivity
  - But only focus on direct communication between vehicles and roadside APs, did not consider inter-vehicular communication

Multihop Relaying

- "A vehicle outside the coverage of any AP depends on other vehicles to relay its packets using inter-vehicular communication, possibly over multiple hops"
  - Can exploit high density of vehicles and resulting greater connectivity opportunities



Multihop Relaying (2)

- Similar strategy found to be beneficial in other contexts
  - Heterogeneous cellular and WiFi networks [Lu et al, Mobicom'03]
  - Mesh, multihop wireless LANs [Banerjee et al, Infocom'04] and home wireless networks [Papagiannaki et al, Infocom'06]
  - Internet connectivity for mobile ad hoc networks (MANETs) [Ruiz et al, IEEE COMM'05]
    - Use random mobility models
- Other related work:
  - Research on inter-vehicular communication or vehicular ad hoc networks (VANETs) focusing on routing, measurements, etc e.g., [Singh et al, TridentCom'06]
    - Do not consider communication with fixed infrastructure
  - Analysis of connectivity properties in hybrid ad hoc networks [Dousse et al, Infocom'02]
    - Focus on connectivity between sparsely distributed fixed wireless nodes with wired infrastructure

Our Work

- Goal: study potential improvement in Internet connectivity with multihop relaying in real-world vehicular environments relative to default "direct access" strategy
  - Also study the impact of communication range
- Metrics
  - Spatial connectivity (at a given time): fraction of vehicles connected
  - Temporal connectivity: duration of (dis-)connection
- Use real AP location data and detailed & realistic vehicular mobility trace for a city scenario (viz. Zurich, Switzerland)

Representative Results

3-4x improvement

Average (median) connection duration (s)	1hop	2hop	3hop
(15dBm, 11Mbps)	66.65 (37)	124.45 (70)	206.24 (166)
(15dBm, 2Mbps)	98.04 (66)	188.37 (152)	252.49 (210)
(15dBm, 1Mbps)	126.73 (84)	320.26 (250)	[illegible]
(19dBm, 1Mbps)	212.36 (195)	372.51 (272)	[illegible]

Reduced disconnection periods

Average (median) disconnection duration (s)	1hop	2hop	3hop
(15dBm, 11Mbps)	61.23 (25)	36.86 (6)	22.42 (1)
(15dBm, 2Mbps)	59.40 (19.34)	29.36 (1)	6.74 (0.69)
(15dBm, 1Mbps)	33.14 (8)	6.33 (0.49)	1.87 (0.38)
(19dBm, 1Mbps)	26.56 (0.91)	2.56 (0.37)	0.49 (0.35)

Results Summary

- Multihop relaying gives substantial gains in connection duration relative to direct access (as much as 400%)
  - Further gains together with increased communication range (~460%)
- Relay paths with few hops are sufficient to realize most of the gain
- Differences between spatial and temporal connectivity behaviors:
  - Multihop relaying vs. direct access with increased communication range
  - Effect of vehicle density

Paper appeared in IEEE Infocom 2007 Workshop on MObile networking for Vehicular Environments (MOVE'07)

Issues for Future Work

- Data transfer performance
  - Impact of multiple access interference and fading
- Mobility management and AP configuration protocols
- Efficient and resilient data forwarding protocols