“A Vertical Handoff Decision Algorithm in Heterogeneous Wireless Networks”

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Presentation Outline

- Heterogeneous Wireless Networks
- Vertical Handoff
- WLAN/Cellular Interconnection
- Current research at UBC:
  - “A vertical handoff decision algorithm for heterogeneous wireless networks”
Heterogeneous Wireless Networks

- Different Access Technologies (radio interfaces) and overlapping coverage.
- Different Network Architectures and Protocols for transport, routing and mobility management.
- Different Service Demands from mobile users (low-data-rate, high-data rate, voice, etc)
- Different Operators in the market.
Horizontal vs. Vertical Handoff [1]

Horizontal Handoff

Vertical Handoff


Handoff Metrics

- Horizontal HO – mainly use received signal strength (RSS) to decide the handoff...
- But Vertical HO?
  - RSS?
  - Offered bandwidth?
  - Price?
  - Power consumption?
  - Speed?
  - ....
Steps of the Vertical Handoff Process

Step 1: “System Discovery”
The MT must know which wireless networks are reachable.

Step 2: “Handoff Decision”
The MT then evaluates the reachable wireless networks to make a decision.

Step 3: “Handoff Execution”
If the MT decides to perform a VHO, it executes the VHO procedure required to be associated with the new wireless network.

WLAN – Cellular Networks

- Important case of heterogeneous wireless networks integration.
- Two architectures are proposed [2]:
  - Tightly-coupled inter-working.
  - Loosely-coupled inter-working.

WLAN – Cellular Networks Integration

Standardization efforts:

- Both 3GPP and 3GPP2 are working in the inter-working with WLAN as an extension of their radio access networks.

- IEEE 802.21 Media Independent Handover Group is working toward the seamless handoffs between:
  - IEEE 802.XX family.
  - IEEE 802.XX and 3G Cellular
  - Between 802.11 ESSs.

Research at UBC: Vertical Handoff Decision Algorithm

- The problem is formulated as a Markov Decision Process (MDP).
- There is a link reward function associated with the QoS of the connection and also a signaling cost function associated with the signaling overhead and processing load of the vertical handoff.
- Both functions are introduced to capture the tradeoffs between the network resources utilized by a connection and the processing load incurred in the network.
- Objective: determine an optimal policy which maximizes the total expected reward per connection.

\[ v^\pi(s) = E^\pi_s \left\{ \sum_{t=1}^{\infty} \lambda^{t-1} r(X_t, Y_t) \right\} \]

where \( v^\pi(s) \) is the total expected reward, given policy \( \pi \) is used with initial state \( s \), and discount factor \( \lambda \).
An MDP model consists of five elements: decision epochs, states, actions, rewards and transitions probabilities.

**Decision Epochs**

\[ X_t, Y_t \]

\[ X_1, X_2, X_3, \ldots, X_N, Y_N \]

\[ 0 \quad 1 \quad 2 \quad 3 \quad \ldots \quad N-1 \quad N \quad \text{time} \]

\( X_t \) denotes the state at decision epoch \( t \).
\( Y_t \) denotes the action chosen at decision epoch \( t \).
\( N \) denotes the time that the connection terminates.

**Model Formulation**

**Vertical Handoff Decision Epochs**
State Space

\[ S = \{1, 2, \ldots, M\} \times B^1 \times D^1 \times B^2 \times D^2 \times \cdots \times B^M \times D^M \]

Network

Units of Bandwidth

\[ B^m = \{1, 2, 3, \ldots, b^m_{\text{max}}\}, \quad m = 1, 2, \ldots, M \]

Units of Delay

\[ D^m = \{1, 2, 3, \ldots, d^m_{\text{max}}\}, \quad m = 1, 2, \ldots, M \]

\( M \) denotes the number of collocated networks.

\( B^m \) denotes set of available bandwidth from network \( m \).

\( D^m \) denotes set of delay from network \( m \).

Rewards

Reward Function

\[ r(s, a) = f(s, a) - g(s, a) \]

\[ f(s, a) = \omega \, f_b(s, a) + (1 - \omega) \, f_d(s, a) \]

Link Reward Function

\[ f_b(s, a) = \begin{cases} 1, & b_a \geq U_B \\ (b_a - L_B)/(U_B - L_B), & L_B < b_a < U_B \\ 0, & b_a \leq L_B \end{cases} \]

Signaling Cost Function

\[ f_d(s, a) = \begin{cases} 1, & 0 < d_a \leq L_D \\ (U_D - d_a)/(U_D - L_D), & L_D < d_a < U_D \\ 0, & d_a \geq U_D \end{cases} \]

\[ g(s, a) = \begin{cases} K_{i, a}, & i \neq a \\ 0, & i = a \end{cases} \]
Actions

\[ A = \{1, 2, \ldots, M\} \]

where \( M \) is the number of collocated networks.

Transition Probabilities

Given the current state \( s = [i, b_j, d_j, \ldots, b_m, d_m] \) and the chosen action be \( a \), the probability function that the next state \( s' = [j, b'_j, d'_j, \ldots, b'_m, d'_m] \) is:

\[
P[s' | s, a] = \begin{cases} 
\prod_{m=1}^{M} P[b'_m, d'_m | b_m, d_m], & j = a \\
0, & j \neq a
\end{cases}
\]

Optimality Equations

Let \( v(s) \) denote the maximum expected reward given initial state \( s \)

\[
v(s) = \max_{s' \in \mathcal{S}} v^*(s')
\]

Then, the optimality equations are given by:

\[
v(s) = \max_{a \in A} \left\{ r(s, a) + \sum_{s' \in \mathcal{S}} \lambda P[s' | s, a] v(s') \right\}
\]

The solutions of the optimality equations correspond to the maximum expected total reward \( v(s) \) and the optimal policy \( \delta^*(s) \).

To solve our problem, the value iteration algorithm was used.
Numerical Results

- Optimal policy versus SAW [4], GRA [5] and two heuristic policies denoted BAN (use de network with more bandwidth), and NEV (never perform a vertical handoff)
  - Expected total reward per connection.
  - Expected number of vertical handoff per connection.

- One decision every 15 seconds.

- Two collocated networks ($M=2$).
  - Network 1 – WLAN ($b_{\text{max}}=25$, $d_{\text{max}}=8$).
  - Network 2 – Cellular system ($b_{\text{max}}=10$, $d_{\text{max}}=8$)

- Application: voice
  - $L_0=2$, $U_0=4$, and bandwidth unit = 16Kbps
  - $L_0=2$, $U_0=7$, and delay unit = 60 ms

State transition probabilities

- Cellular System

$$P[b'_2, d'_2 \mid b_2, d_2] = \begin{cases} 1, & b'_2 = b_2, d'_2 = d_2 \\ 0, & \text{otherwise.} \end{cases}$$

- WLAN

  - Simulation-based approximation.
  - A IEEE 802.11b WLAN is simulated using ns-2[6], with users arriving and departing according to Poisson processes.
  - The traffic is Constant Bit Rate (CBR) under UDP.

Numerical Results

Figure 1 (a) Expected total reward and 1 (b) expected number of vertical handoff versus switching cost $K_{i,a}$ with $\lambda=0.975$ and $\omega=0.25$.

Figure 2 (a) Expected total reward and 2 (b) expected number of vertical handoff versus discount factor $\lambda$ with switching cost $K_{i,2}=K_{2,i}=1$ and $\omega=0.25$. 
Summary of Results

- The MDP scheme gives higher expected total reward and lower expected number of vertical handoff than SAW and GRA.
- The MDP model can be applied to a wide range of conditions.
  - Link reward function (e.g., real-time, non-real-time).
  - Signaling cost function ($K_i$, re-routing complexity, roaming)
- Tradeoff between network resources utilized by the connection and the signaling load incurred in the network.
- Extend the MDP model and simulation model.

Summary:

- Heterogeneous Wireless Networks
- Vertical Handoff
- WLAN/Cellular Inter-working
- Research at UBC
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Thank You!