TRAFFIC-TRACING GATEWAY (TTG)

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NETWORKS LAB GROUP MEETING (1/11/2011)
INTRODUCTION

• **Network Planning**
  - Provide good service
  - Reduce deployment cost

• **Network Planning in wireless networks**
  - Temporal variation of user mobility
  - Variable traffic demand

• But, traffic changes are highly predictable
• User traffic has fixed patterns of movement over time
INTRODUCTION

Example patterns

• **Cellular traffic: Large amount of traffic**
  • In residential areas during early morning and at night
  • In commercial areas during working hours
  • Restaurants/shopping malls in the evening

• **WiFi network in a university setting**
  • Holidays and early morning – residential areas
  • School time – academic buildings
  • Lunch/dinner time – cafes and restaurants
TRAFFIC-TRACING GATEWAY (TTG)

• **Traffic-Tracing Gateway system**
  - Fixed architecture provides basic coverage
  - TTGs provide additional coverage to relieve congestion
  - Possible to derive optimal trajectories

• **Interfaces**
  - Both backbone and access links are wireless
  - Heterogeneous wireless network is the choice
  - Access interface – smaller transmission range for efficient spectrum reuse
  - Backbone interface – Larger transmission range and higher capacity
TRAFFIC-TRACING GATEWAY (TTG)

Fig. 1. Network Structure of TTG
PROBLEM DEFINITION

Problem Statement:

To determine TTG trajectories according to the traffic density distribution.

Constraints:

• Speed: If the location of a TTG is \([x_i(t), y_i(t)]\) at time \(t\), and speed of TTG is \(S\),

\[
\dot{x}_i(t)^2 + \dot{y}_i(t)^2 \leq S^2
\]

• Transmission Range:

\[
[u, v] \in C_i \iff (u - x_i(t))^2 + (v - y_i(t))^2 \leq R^2
\]
FORMULATION

\[ \mathcal{D} = \bigcup_{i=1}^{N} C_i([x_i(t), y_i(t)]). \]
ANALYSIS

Variables:

\[ J^i(k, l, h) = \begin{cases} 
1 & \text{if } [k, l, h] \in C_i \\
0 & \text{if } [k, l, h] \notin C_i.
\end{cases} \]

\[ I(k, l, h) = \begin{cases} 
1 & \text{if } \sum_{i=1}^{N} J^i(k, l, h) \geq 1 \\
0 & \text{if } \sum_{i=1}^{N} J^i(k, l, h) = 0.
\end{cases} \]

Objective Function:

\[ \Omega = \max_{D} \sum_{k=1}^{n_x} \sum_{l=1}^{n_y} \sum_{h=1}^{n_z} I(k, l, h) f(k, l, h) \]
ANALYSIS

At any time $h$, $N$ TTGs are present at locations, $[\bar{x}(h), \bar{y}(h)]$
where,

$$\bar{x}(h) = [x_1(h), x_2(h), \ldots, x_N(h)]$$
$$\bar{y}(h) = [y_1(h), y_2(h), \ldots, y_N(h)]$$

Other definitions

• $F(\bar{x}, \bar{y}, h)$ : Traffic density covered by $N$ TTGs located at $[\bar{x}(h), \bar{y}(h)]$ at time slot $h$

$$F(\bar{x}, \bar{y}, h) = \sum_{k=1}^{n_x} \sum_{l=1}^{n_y} I(k, l, h) f(k, l, h)$$

• $V(\bar{x}, \bar{y}, h)$ : Maximum traffic TTGs can cover from $h$ to $n_t$ if they start moving from $[\bar{x}(h), \bar{y}(h)]$
ANALYSIS

• $V(\bar{x}, \bar{y}, 1)$ : is the maximum traffic covered by TTGs if they start at a point $[\bar{x}, \bar{y}]$ from the beginning

• The maximum value of $V(\bar{x}, \bar{y}, 1)$ for all such $[\bar{x}, \bar{y}]$ is the solution of the objective function

$$\max_{[\bar{x}(1), \bar{y}(1)]} \left( V(\bar{x}, \bar{y}, 1) \right) = \Omega.$$ 

• Fixed base stations in the analysis

$$x_i(t) = x_i \text{ and } y_i(t) = y_i.$$ 

$$\dot{x}_i(t)^2 + \dot{y}_i(t)^2 \leq 0.$$
LIMITED TTG CAPACITY

- Analysis assumed unlimited TTG capacity
- Cooperation among TTGs for serving all the traffic
- A routing strategy is necessary for effective service

\[
a^i(k, l, h) : \text{Fraction of traffic from point } [k, l] \text{ forwarded by TTG } i, \text{ at time interval } h,
\]

\[0 \leq a^i(k, l, h) \leq 1.\]
LIMITED TTG CAPACITY

Without limited TTG capacity assumption

\[ F(\vec{x}, \vec{y}, h) = \sum_{k=1}^{n_x} \sum_{l=1}^{n_y} I(k, l, h) f(k, l, h) \]

With limited TTG capacity assumption

\[ F(\vec{x}, \vec{y}, h) = \max_{a^i(k, l, h)} \sum_{k=1}^{n_x} \sum_{l=1}^{n_y} \sum_{i=1}^{N} a^i(k, l, h) f(k, l, h) \]
SIMULATION

• Simulation setup
  • Testbed implemented in Qualnet
  • WiFi - Access interface
  • 3G (HSDPA) – Backbone interface
  • Traffic – Constant bit rate (CBR) over UDP

• CBR applications to compare performance in terms of throughput, delay and packet loss rate
SCENARIO-1

Supplementing an existing network with TTGs

Urban WiFi network

- Three areas - Transit, Commercial, Residential
- Two fixed base stations and one TTG in each area
- One fixed traffic generator in each area
- Three mobile traffic generators

- Comparison of system performance
  - Fixed base stations only (NO-TTG)
  - Fixed base station and TTGs (TTG)
RESULTS

Scenario 1
RESULTS

Scenario 1
SCENARIO-2

Urban WiFi network

- Three areas - Transit, Commercial, Residential
- 10 base stations including both fixed base stations and TTGs

Comparison of system performance

- Fixed base stations only (NO-TTG)
- Fixed base station and TTGs (TTG)
RESULTS

Scenario 2

![Graphs showing throughput and packet loss rate vs. CBR rate for different TTG percentages.](image)
RESULTS

Scenario 2
CONCLUSION

• TTG – A novel network component

• TTG system
  • Can locate areas with weak wireless connections or congestion
  • Provide better coverage and relieve congestion

• Metrics show significant improvement
  • Throughput
  • Packet loss rate
  • Delay
Algorithm 1: Search Optimal Trajectories of N TTGs.

1. **input**: $\forall[\bar{x}, \bar{y}, h], F(\bar{x}, \bar{y}, h)$
2. **output**: $\Omega$, Optimal trajectories $\forall h, [\bar{x}^*(t), \bar{y}^*(t)]$
3. Initial $\Omega = 0$, and
   \[
   \forall[\bar{x}, \bar{y}], V(\bar{x}, \bar{y}, n_t) = F(\bar{x}, \bar{y}, n_t), P(\bar{x}, \bar{y}, n_t) = [\bar{x}, \bar{y}] \;
   \]
4. for $h \leftarrow (n_t - 1)$ to 1 do
5.   foreach $\forall[\bar{x}, \bar{y}], 0 \leq x_i \leq n_x, 0 \leq y_i \leq n_y$ do
6.     foreach $i \leftarrow 1$ to $N$ do
7.        Compute numerical derivative $[\frac{\partial V}{\partial x_i}, \frac{\partial V}{\partial y_i}]$
8.        \[
     [dx_i^*, dy_i^*] = \arg\max\left\{\frac{\partial V}{\partial x_i} dx_i^* + \frac{\partial V}{\partial y_i} dy_i^*\right\} \;
     \]
9.        $\frac{\partial V}{\partial h_i} = -F(\bar{x}, \bar{y}, h) - \sum_{i=1}^{N} \left\{\frac{\partial V}{\partial x_i} dx_i^* + \frac{\partial V}{\partial y_i} dy_i^*\right\} \;
10. \quad V(\bar{x}, \bar{y}, h) = V(\bar{x}, \bar{y}, h + 1) - \frac{\partial V}{\partial h} \;
11. \quad P(\bar{x}, \bar{y}, h) = [\bar{x} + d\bar{x}^*, \bar{y} + d\bar{y}^*] \;
12. \quad \Omega = \max_{[\bar{x}, \bar{y}]} \{V(\bar{x}, \bar{y}, 1)\} \;
13. \quad [\bar{x}^*(1), \bar{y}^*(1)] = \arg\max_{[\bar{x}, \bar{y}]} \{V(\bar{x}, \bar{y}, 1)\} \;
14. for $h \leftarrow 2$ to $n_t$ do
15.   \[
   [\bar{x}^*(h), \bar{y}^*(t)] = P(\bar{x}^*(t), \bar{y}^*(t), h - 1) \;
   \]
16. return $\Omega$, and $[\bar{x}^*(t), \bar{y}^*(t)]$