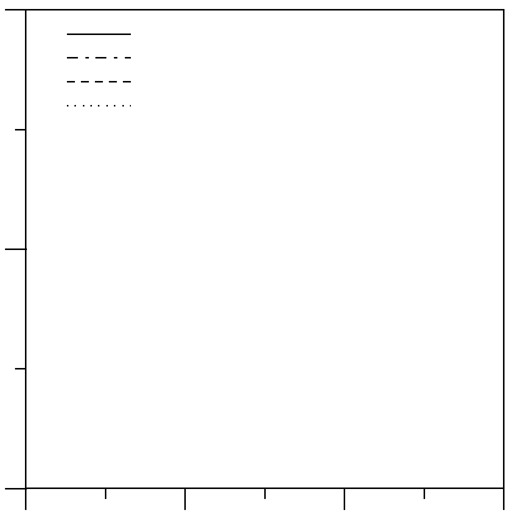
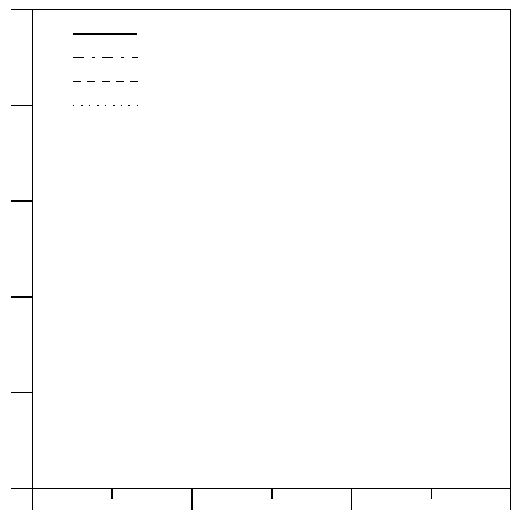
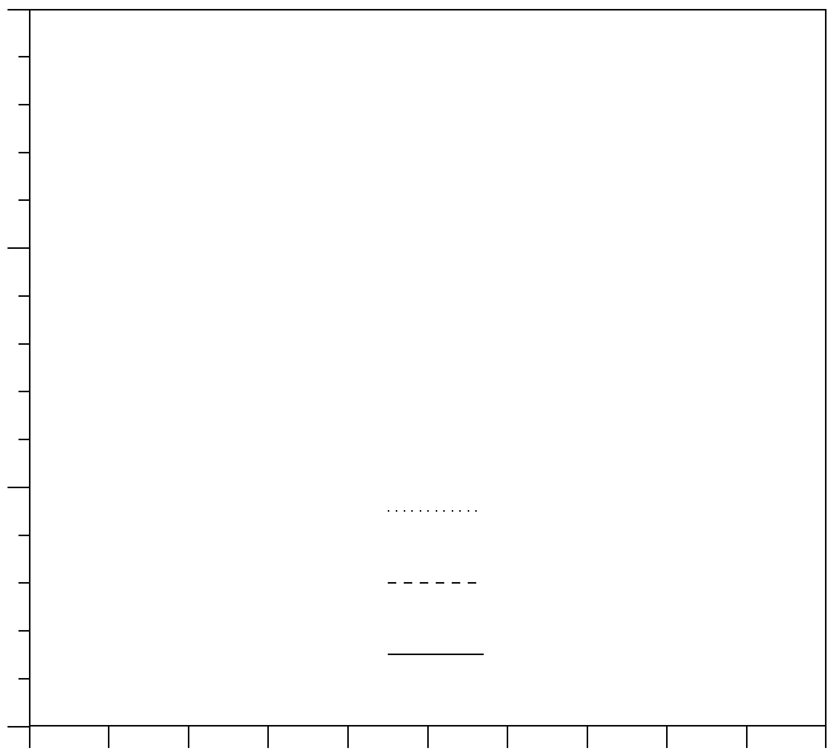
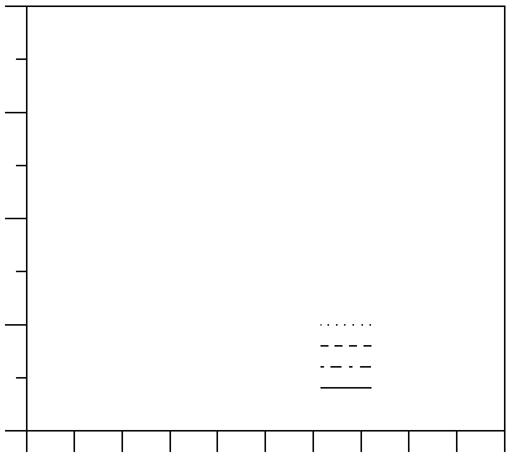
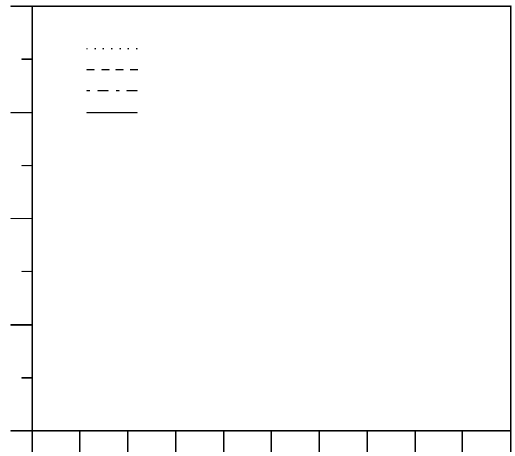
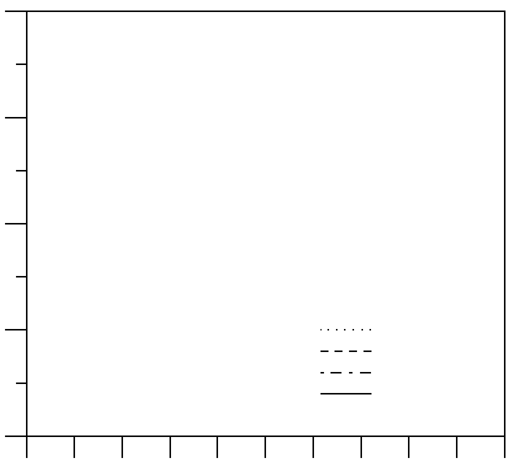
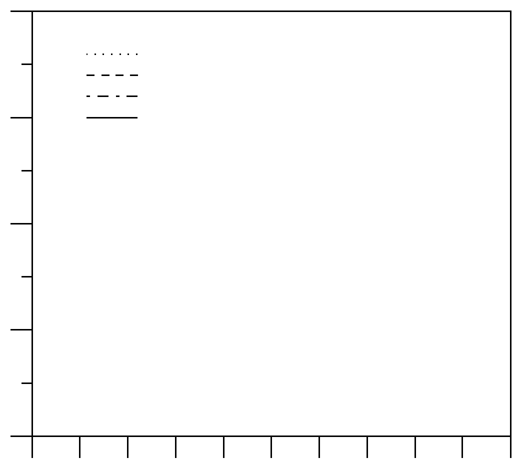
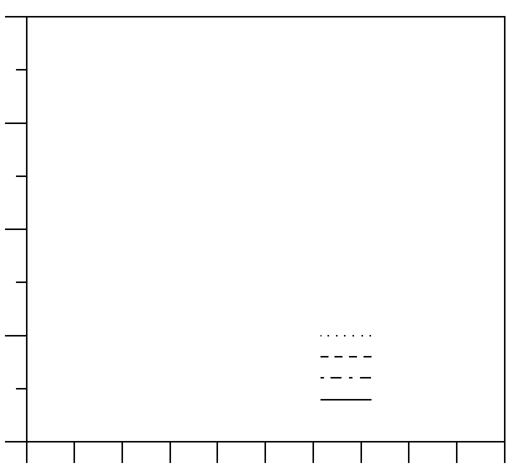
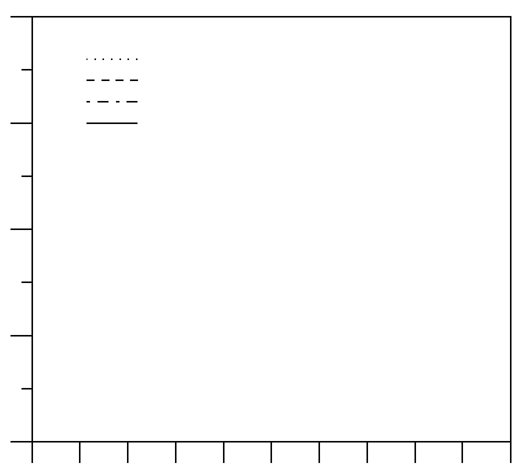
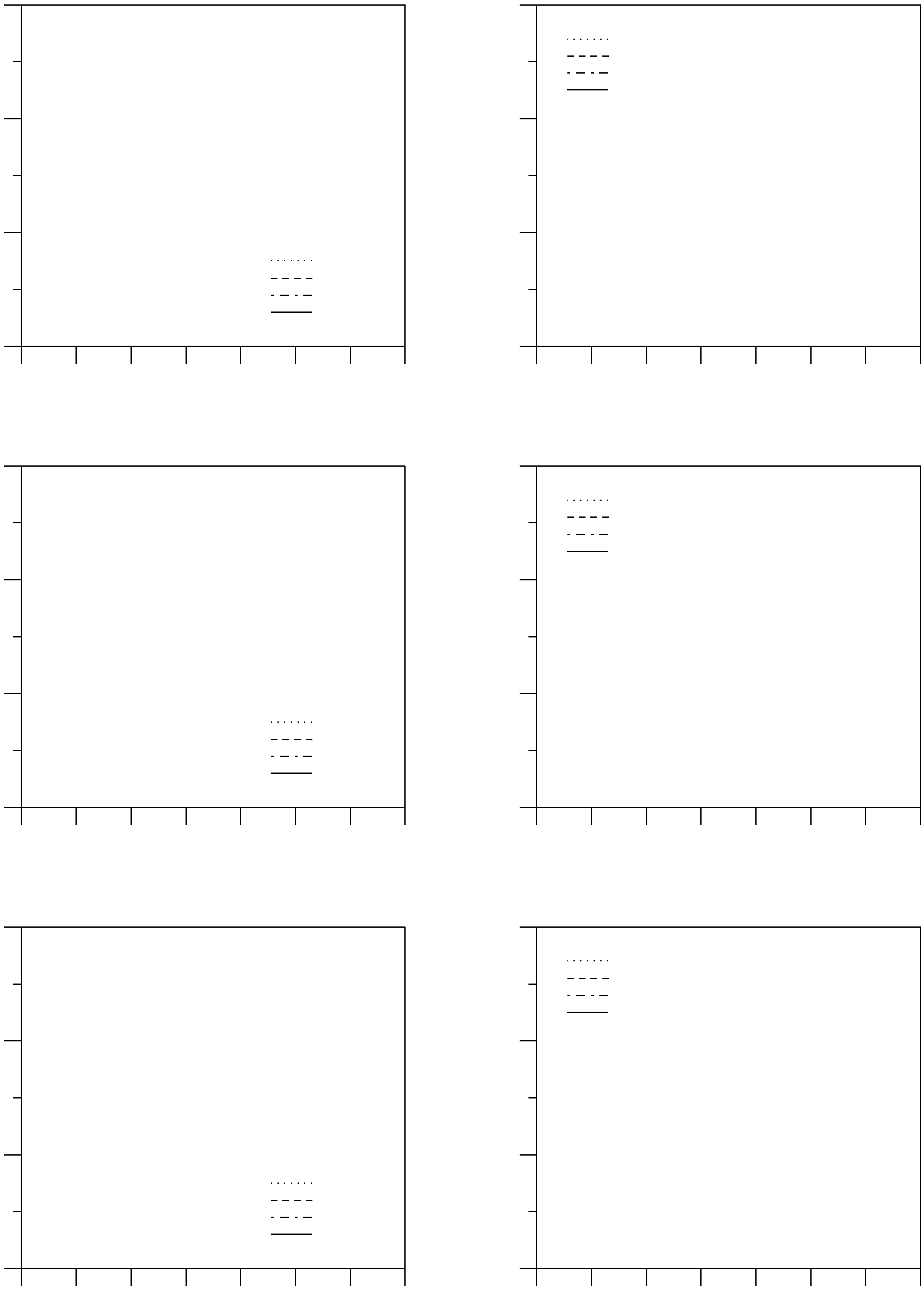
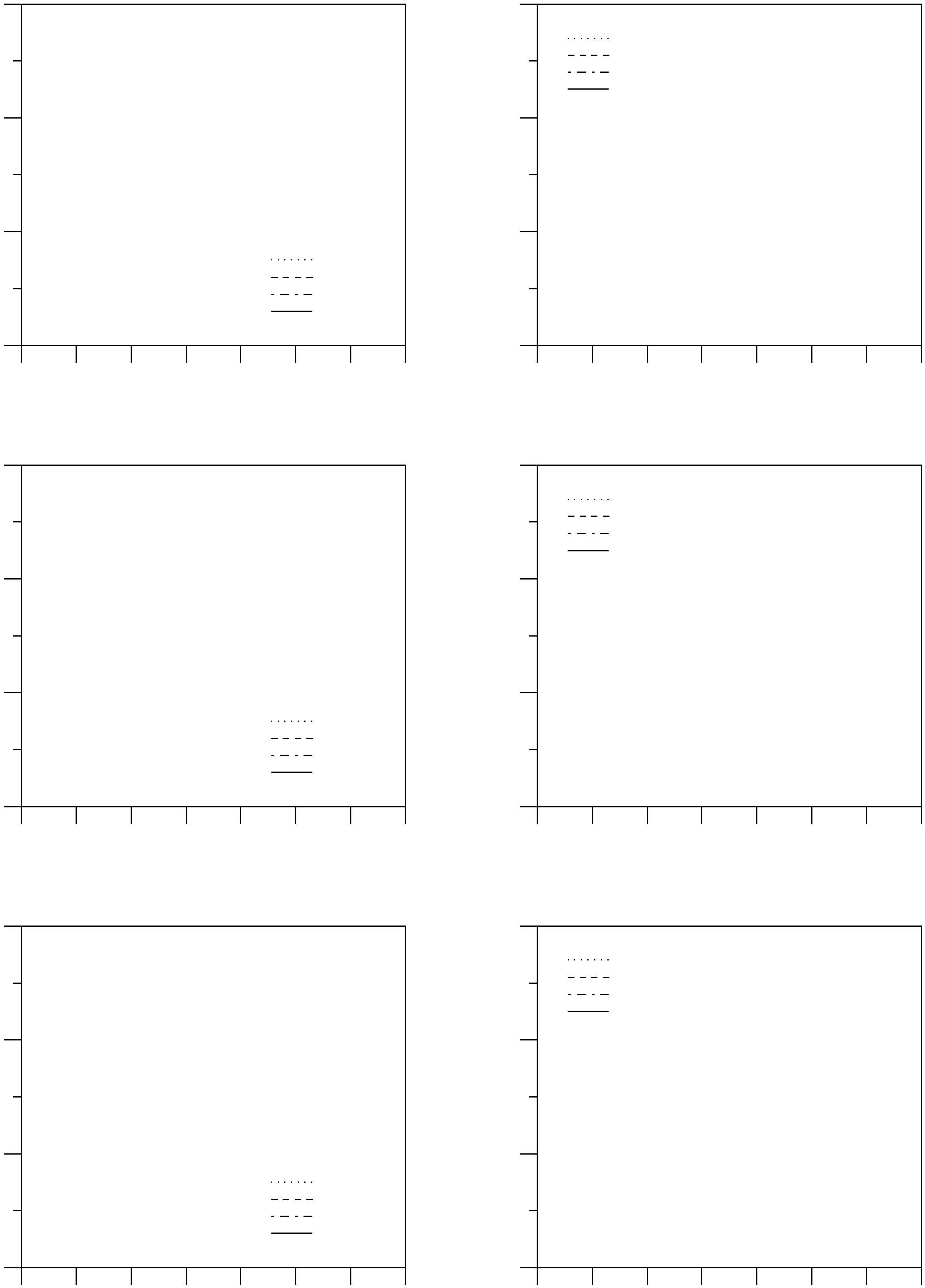


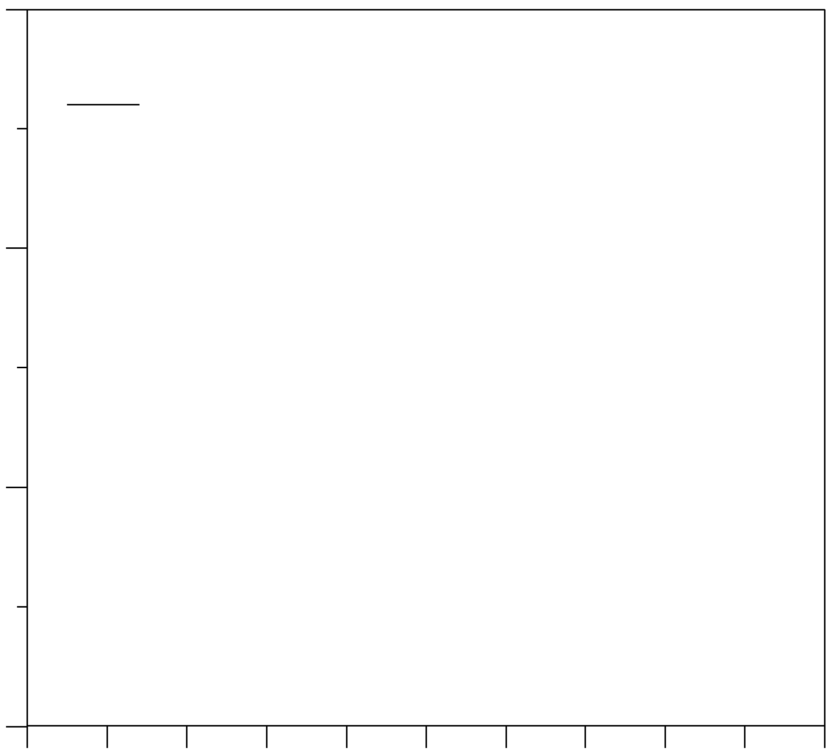


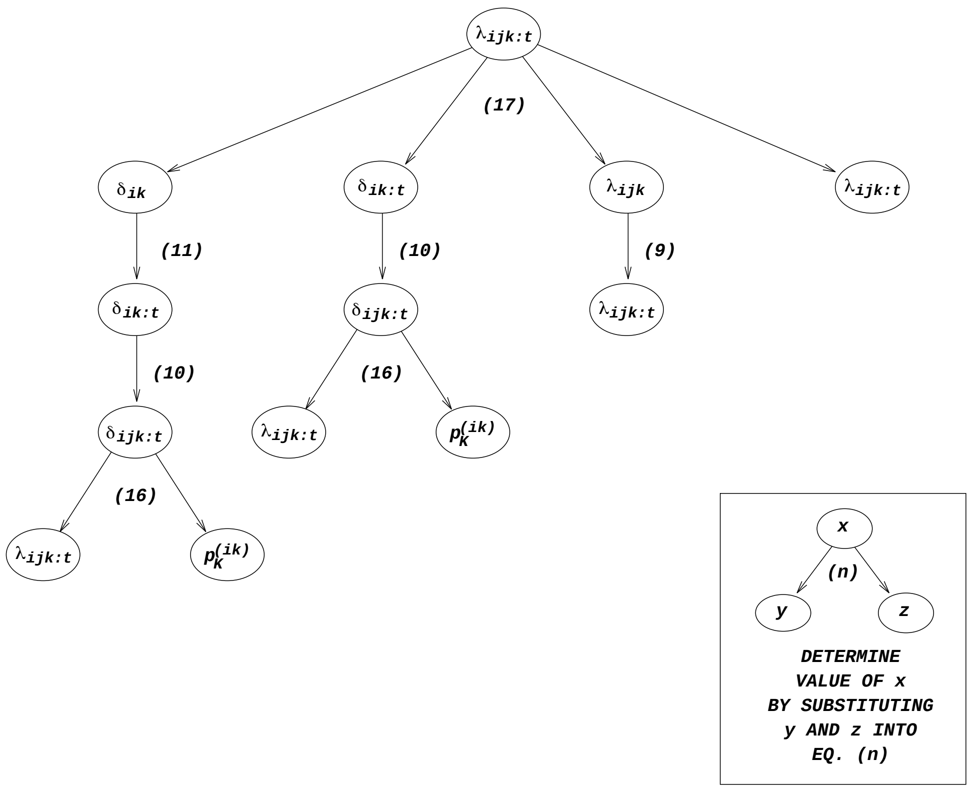


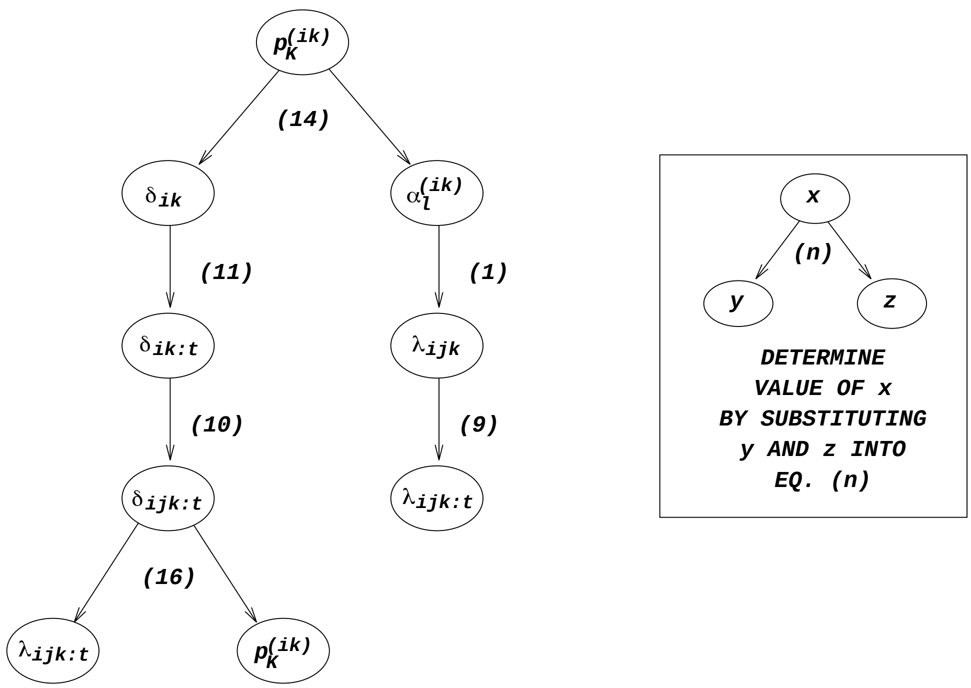




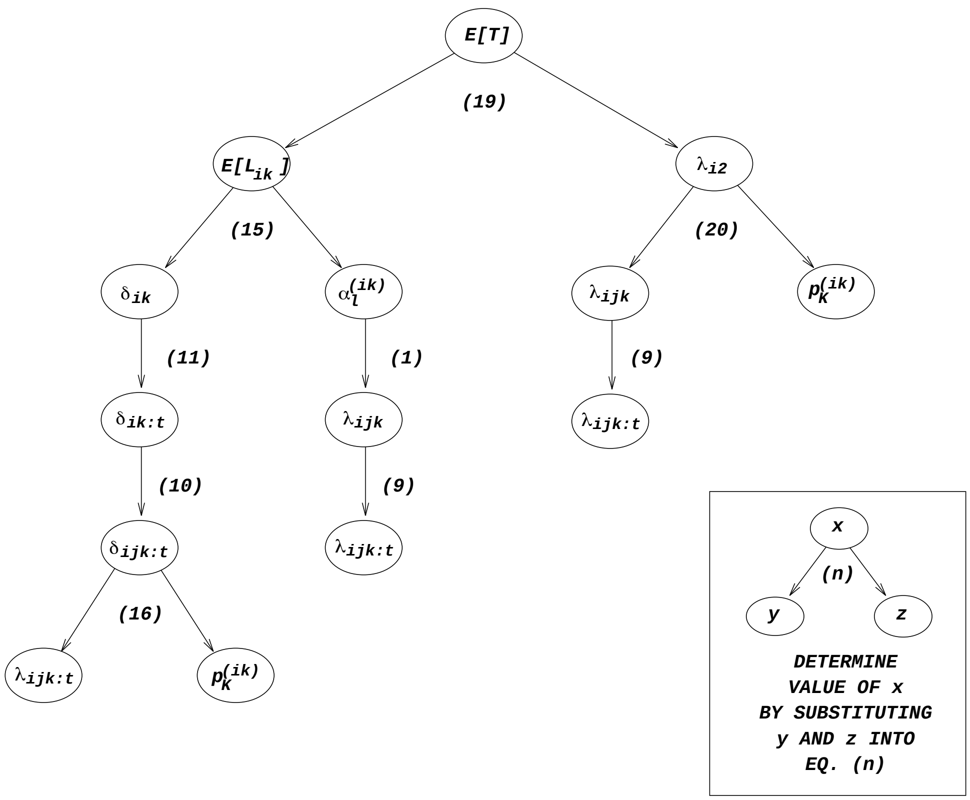


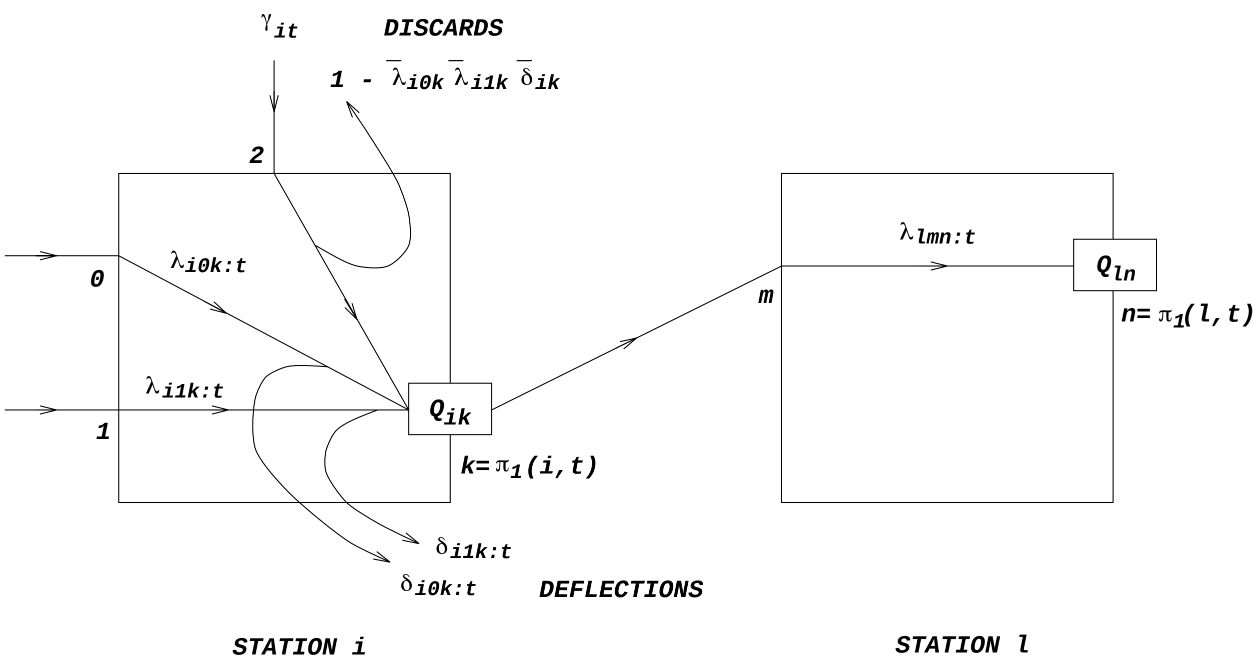


λ ijk:t
(17)
δ ik
δ ik:t
λ ijk
λ ijk:t
(11)
(10)
(9)
δ ik:t
δ ijk:t
λ ijk:t
(10)
(16)
δ ijk:t
λ ijk:t
p K (ik)
(16)
λ ijk:t
p K (ik)
x
(n)
y
z
DETERMINE
VALUE OF x
BY SUBSTITUTING
y AND z INTO
EQ. (n)

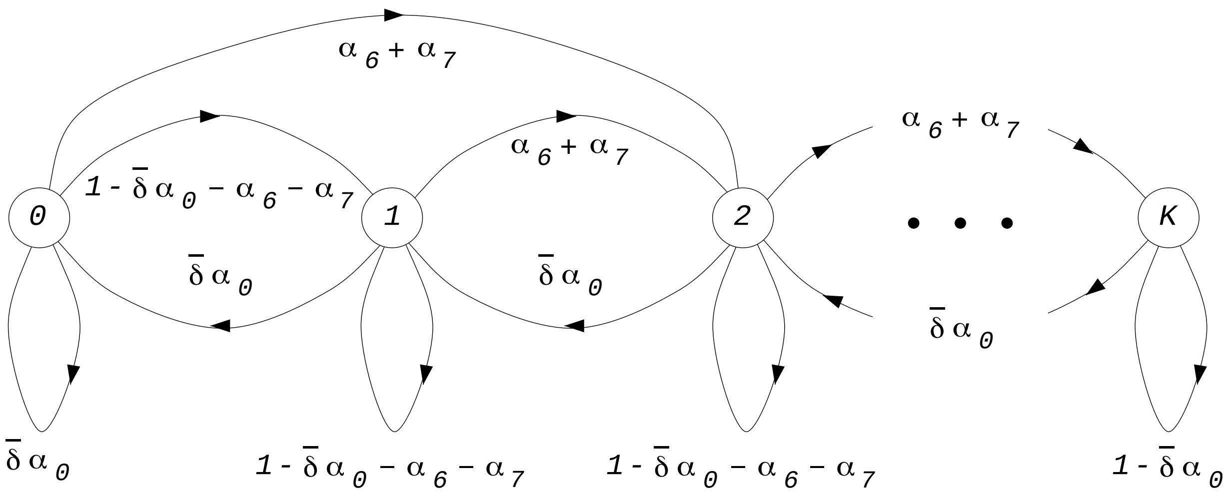


$p_K^{(ik)}$
(14)
δ_{ik}
$\alpha_l^{(ik)}$
(11)
(1)
$\delta_{ik:t}$
λ_{ijk}
(10)
(9)
$\delta_{ijk:t}$
$\lambda_{ijk:t}$
(16)
$\lambda_{ijk:t}$
$p_K^{(ik)}$
x
(n)
y
z
DETERMINE
VALUE OF x
BY SUBSTITUTING
y AND z INTO
EQ. (n)

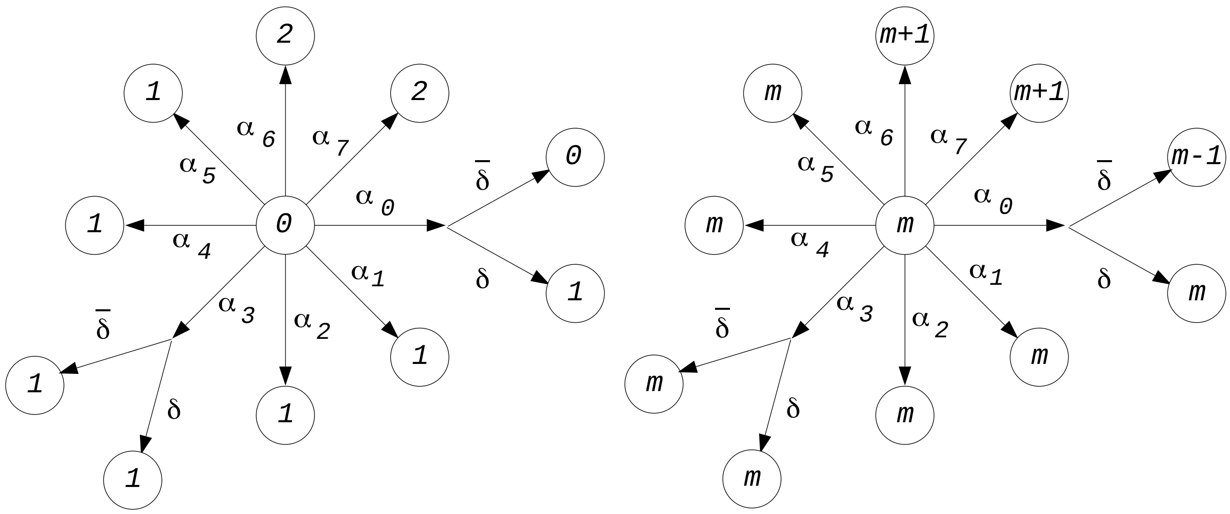

E[T]
(19)
E[L_ik]
λ_i2
(15)
(20)
δ_ik
α_l^(ik)
λ_ijk
p_k^(ik)
(11)
(1)
(9)
δ_ik:t
λ_ijk
λ_ijk:t
(10)
(9)
δ_ijk:t
λ_ijk:t
(16)
λ_ijk:t
p_k^(ik)
x
(n)
y
z
DETERMINE
VALUE OF x
BY SUBSTITUTING
y AND z INTO
EQ. (n)



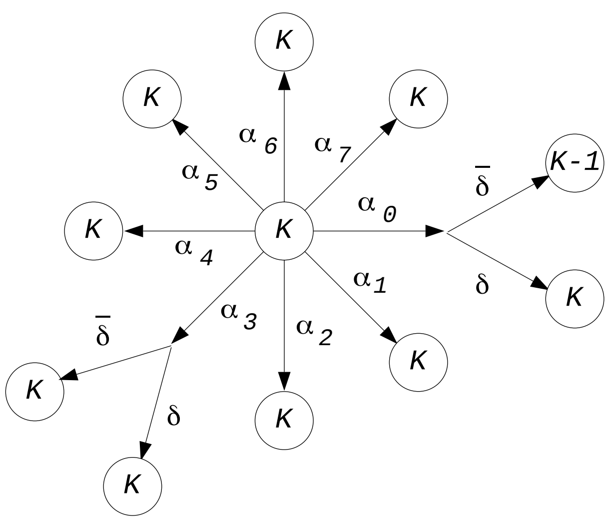
γ_{it}
DISCARDS
$1 - \bar{\lambda}_{i0k}\,\bar{\lambda}_{i1k}\,\bar{\delta}_{ik}$
2
0
$\lambda_{i0k:t}$
$\lambda_{i1k:t}$
1
Q_{ik}
$k=\pi_1(i,t)$
$\delta_{i1k:t}$
$\delta_{i0k:t}$
DEFLECTIONS
$\lambda_{lmn:t}$
m
Q_{ln}
$n=\pi_1(l,t)$
STATION i
STATION l



α 6 + α 7
1 - δ̄ α 0 - α 6 - α 7
α 6 + α 7
α 6 + α 7
0
1
2
K
δ̄ α 0
δ̄ α 0
δ̄ α 0
δ̄ α 0
1 - δ̄ α 0 - α 6 - α 7
1 - δ̄ α 0 - α 6 - α 7
1 - δ̄ α 0



$0 < m < K$



$$\alpha_0 \triangleq \bar{\lambda}_0\bar{\lambda}_1\bar{\lambda}_2$$

$$\alpha_1 \triangleq \lambda_0\bar{\lambda}_1\bar{\lambda}_2$$

$$\alpha_2 \triangleq \bar{\lambda}_0\lambda_1\bar{\lambda}_2$$

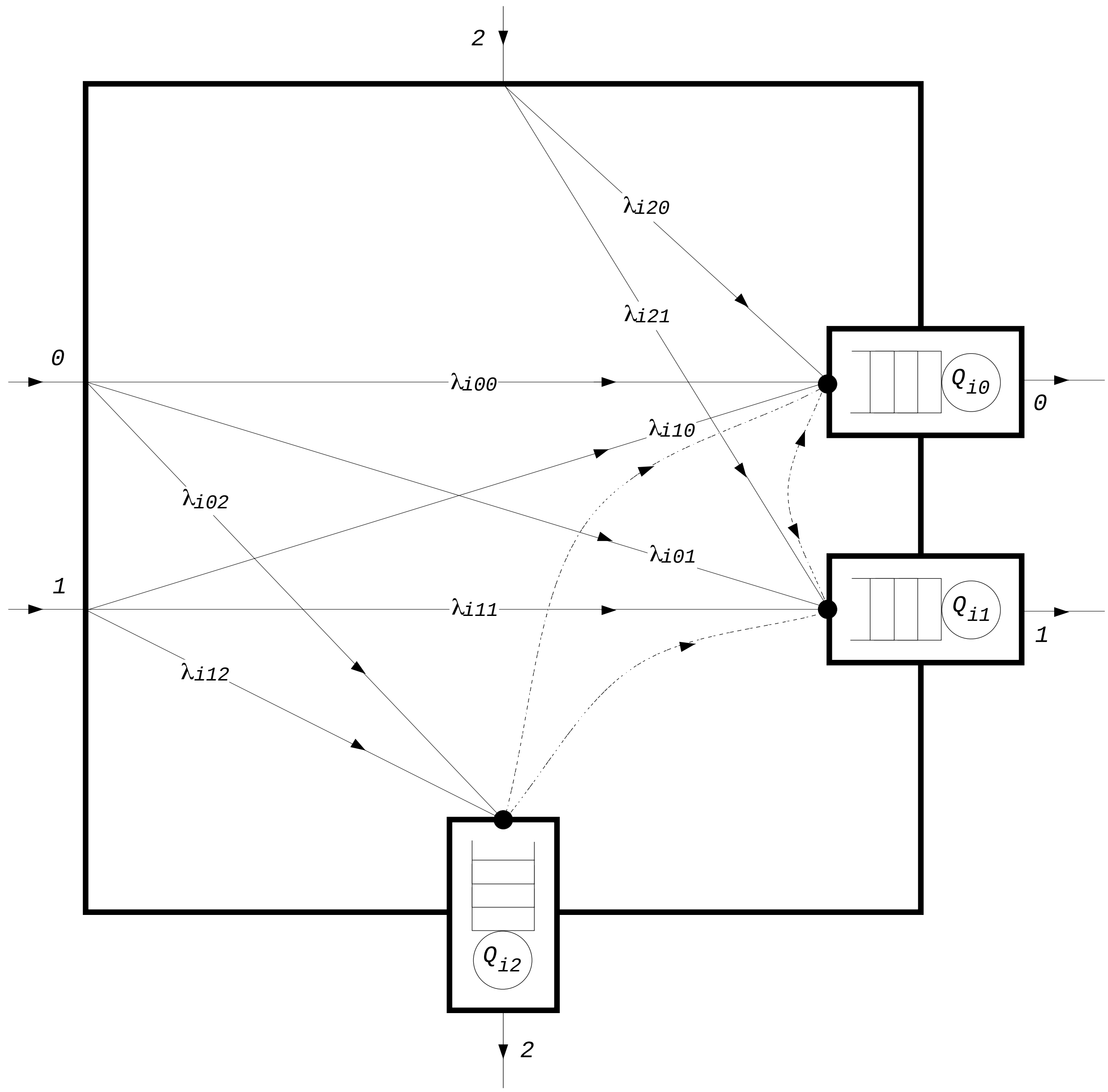
$$\alpha_3 \triangleq \bar{\lambda}_0\bar{\lambda}_1\lambda_2$$

$$\alpha_4 \triangleq \bar{\lambda}_0\lambda_1\lambda_2$$

$$\alpha_5 \triangleq \lambda_0\bar{\lambda}_1\lambda_2$$

$$\alpha_6 \triangleq \lambda_0\lambda_1\bar{\lambda}_2$$

$$\alpha_7 \triangleq \lambda_0\lambda_1\lambda_2$$



STATION i

fl

X

ξ

A **A**

∇

Acknowledgments

Z Z

References

4

GL B *3*

6 *ffi*

Z Z

$\boldsymbol{G}$

h

h

$(i\ j \rightarrow l\ m)$ j i m l

K

L

L_k $\mathcal{Q}_k$

$_j$ j

$_k$ $\mathcal{Q}_k$

$_{jk}$ $i\ j\ k$

$_{jkt}$ $i\ j\ k$

$_{jk}$ $_{jk}$

$_{jkt}$ $_{jkt}$

N

p_m m

$p_m^{(n)}$ m

$p_m^{(k)}$ m $\mathcal{Q}_k$

p i

$p_m^{(k)}$ $p_m^{(j)}$

$\mathbf{p}$

$\mathbf{P}$

$\pi_n\ i$ i

$\mathcal{Q}_k$ k i

$\sum$

x i

x x x

ξ ∇h $/\mathbf{A}$ ^{2} ∇h $\mathbf{A}$ $\mathbf{A}$ $\mathbf{b}$ ξ

h ξ $/$ ξ ξ

$$\left.\frac{h \quad \xi}{\xi}\right|_{\xi} \quad \xi \;\; \mathbf{A} \quad ^2 + \sum \mathbf{A} \quad \mathbf{A} \quad b$$

$$\frac{\nabla h}{\mathbf{A} \quad ^2} \mathbf{A} \quad ^2 + \sum \mathbf{A} \quad \mathbf{A} \quad b$$

$$\mathbf{A} \quad \mathbf{A} \quad \mathbf{b} + \sum \mathbf{A} \quad \mathbf{A} \quad b$$

$$\sum \quad \mathbf{A} \quad \mathbf{A} \quad b \quad + \sum \mathbf{A} \quad \mathbf{A} \quad b$$

h ξ $/$ ξ ξ ^2h ξ $/$ $\xi^2 \geq$ h ξ

D Notation

$a_{\;j}$ $\mathbf{A}$

$\mathbf{A}$

$\mathbf{A}$ i $\mathbf{A}$

$_j$

$^{(\;k)}_{j}$ $\mathcal{Q}_{\;k}$

$^{(\;k)}_{j}$ $^{(\;k)}_{j}$

b $\mathbf{b}$

$\mathbf{b}$

β

$_{st}$ s

$d\;\;s$ s

$y/\;\;x$ y

$^2y/\;\;x^2$ y

δ

$\delta_{\;k}$ $\mathcal{Q}_{\;k}$

$\delta_{\;k\;t}$ $\mathcal{Q}_{\;k}$

$\delta_{\;jk\;t}$ i j k

$\Delta\beta$

$\partial y/\partial x$ y

$c_1 \; c_2 \; \ldots \; c_n \quad \overset{\Delta}{} \mathbf{A} \quad \mathbf{b}$

$$c \overset{\Delta}{} \sum_j a \; {}_j x_j \quad b$$

$a'_k \quad \mathbf{A} \quad a'_k \overset{\Delta}{} a \; {}_k$

$$\nabla h \qquad \left[\sum a'_k \left(\sum_j a \; {}_j x_j \quad b\right)\right]_{k=1}^{n}$$
$$\left[\sum a'_k \; c\right]_{k=1}^{n}$$
$$\mathbf{A} \quad \mathbf{A} \quad \mathbf{b}$$

C Derivation of an expression for the minimizing scalar

ξ_n

$$h \quad \xi \overset{\Delta}{} h \quad + \xi$$

h

$$h \qquad - \mathbf{A} \quad \mathbf{b}^{\;2}$$

$\mathbf{A} \quad i \quad \mathbf{A} \quad h$

$$\frac{h \quad \xi}{\xi} \qquad \frac{}{\xi} - \; \mathbf{A} \quad + \xi \quad \mathbf{b}^{\;2}$$
$$\frac{}{\xi} - \left| \begin{array}{c} \mathbf{A}_1 \quad + \xi \mathbf{A}_1 \quad b_1 \\ \\ \mathbf{A}_n \quad + \xi \mathbf{A}_n \quad b_n \end{array} \right|^2$$
$$\frac{}{\xi} - \sum \xi \mathbf{A} \quad + \mathbf{A} \quad b^{\;2}$$
$$\frac{}{\xi} - \sum \xi^2 \; \mathbf{A} \quad {}^2 + \; \xi \; \mathbf{A} \quad \mathbf{A} \quad b \; + \; \mathbf{A} \quad b^{\;2}$$
$$\xi \; \mathbf{A} \quad {}^2 + \sum \mathbf{A} \quad \mathbf{A} \quad b$$

$$\frac{{}^2 h \quad \xi}{\xi^2} \quad \mathbf{A} \quad {}^2$$

$$p_1 \quad p_0 \frac{\delta \quad _0}{\delta \quad _0}$$

p_2 p_1 p_0

$$p_2 \quad p_0 \frac{_6 + \quad _7}{\delta \quad _0 \; ^2}$$

$$p_3 \quad p_0 \frac{_6 + \quad _7 \; ^2}{\delta \quad _0 \; ^3}$$

$p_m \quad \leq m \leq K$

$$p_m \quad p_0 \frac{_6 + \quad _7 \; ^{m-1}}{\delta \quad _0 \; ^m}$$

p_0

$$p_0 + p_0 \frac{\delta \quad _0}{\delta \quad _0} + \sum_{m=2}^{K} p_0 \frac{_6 + \quad _7 \; ^{m-1}}{\delta \quad _0 \; ^m} \quad p_0 \left[\; + \frac{\delta \quad _0}{\delta \quad _0} + \sum_{m=2}^{K} \frac{_6 + \quad _7 \; ^{m-1}}{\delta \quad _0 \; ^m} \right]$$

$$p_0 \quad \frac{\delta \quad _0 \; ^K \delta \quad _0 \quad _6 \quad _7}{\delta \quad _0 \; ^K \quad _6 + \quad _7 \; ^K}$$

$$p_1 \quad \frac{\delta \quad _0 \; \delta \quad _0 \quad _6 \quad _7 \; \delta \quad _0 \; ^{K-1}}{\delta \quad _0 \; ^K \quad _6 + \quad _7 \; ^K}$$

$\leq m \leq K$

$$p_m \quad \frac{\delta \quad _0 \quad _6 \quad _7 \; \delta \quad _0 \; ^{K-m} \quad _6 + \quad _7 \; ^{m-1}}{\delta \quad _0 \; ^K \quad _6 + \quad _7 \; ^K}$$

B Derivation of the expression for the gradient vector

$^{\Delta}$ x_1 x_2 $\ldots$ x_n — $\mathbf{b}$ $^{\Delta}$ b_1 b_2 $\ldots$ b_n $\mathbf{A}$ $^{\Delta}$ — $a \;_j$ h h $\mathbf{A}$ $\mathbf{b}$ $^2/$ h

$$\nabla h \quad \left[\frac{\partial h}{\partial x_k} \right]_{k=1}^{n}$$

$$\left[\frac{\partial}{\partial x_k} - \sum \left(\sum_j a \;_j x_j \quad b \right)^2 \right]_{k=1}^{n}$$

$$\left[a \;_k \left(\sum \sum_j a \;_j x_j \quad b \right) \right]_{k=1}^{n}$$

,

Appendix

A Markov-chain solution

$$p_0 \quad \delta \ _0 \quad p_1 \delta \ _0$$

$$p_1 \ \delta \ _0 + \ _6 + \ _7 \quad p_0 \quad \delta \ _0 \quad _6 \quad _7 \ + p_2 \delta \ _0$$

$$p_2 \ \delta \ _0 + \ _6 + \ _7 \quad p_0 \ _6 + \ _7 \ + p_1 \ _6 + \ _7 \ + p_3 \delta \ _0$$

$$p_m \ \delta \ _0 + \ _6 + \ _7 \quad p_{m-1} \ _6 + \ _7 \ + p_{m+1} \delta \ _0$$

$\leq m < K$

N

, , , , ; , , , ,

i $i+m$

N m $\leq i < N$

7 Conclusion

— —

— —

— N —

X

$$X \le x \quad \begin{cases} \quad x \le \\ x \quad < x < \\ \quad x \ge \end{cases}$$

X

$$X \le x \quad \begin{cases} \quad x \le \\ e^{-x} \quad x > \end{cases}$$

X

a $a >$

$$X \quad k \quad \begin{cases} /a \quad k \quad a \\ /a \quad k \\ \end{cases}$$

— —

X ;

X^2 $_j$ X

a

a

$_j$

^{j}

$\Delta \sum \sum_j \; _j$

^{j}

$\sum_j \; _j$ i i

i

N

∇h

ξ_n

$\sum \sum_j \quad j$

$_{jk} < \quad _{jk} >$

$\beta \; _{st} \quad \beta \quad < \beta <$

β

0

$n \quad n$

n

$\beta + \Delta\beta \; _{st} \quad \Delta\beta$

$_{st}$

6 Modeling results

$_{st}$

X

$$_{st} \quad \begin{cases} X & s \; / \\ & s \end{cases}$$

$X \quad _{st}$

X

$\mathbf{A}$ N^2 N^2 $\mathbf{b}$ N^2

$$h \quad \stackrel{\Delta}{} - \mathbf{A} \quad \mathbf{b}^{2}$$

h

h $_0$

$_1$ $_2$ $\cdots$

$$_{n+1} \stackrel{\Delta}{} \quad _n + \xi_n \nabla h \quad _n$$

h h ; ξ_n ξ

h $_n + \xi \nabla h$ $_n$ h

$\mathbf{A}$ h

$$\nabla h \quad \mathbf{A} \quad \mathbf{A} \quad \mathbf{b}$$

$\mathbf{A}$ $\mathbf{A}$ N^2 N^2

$$\mathbf{A} \; i \quad l \; s \quad \begin{cases} & \exists m \; i \; \pi_1 \; i \quad \rightarrow \; l \; m \quad s \\ _t & l \quad i \quad s \\ _t & l \quad i \; \pi_1 \; l \; s \quad \pi_1 \; i \quad s \, / \\ & \end{cases}$$

$$\mathbf{A} \quad l \; s \quad i \quad \begin{cases} & \exists m \; i \; \pi_1 \; i \quad \rightarrow \; l \; m \quad s \\ _{ls} & i \quad l \quad s \\ _{ls} & i \quad l \; \pi_1 \; l \; s \quad \pi_1 \; i \quad / \, s \\ & \end{cases}$$

$\leq i \leq N$ $\leq$ $\leq N$ $\leq l \leq N$ $\leq s \leq N$

;

N

ξ_n ξ_n

$$\xi_n \quad \frac{\nabla h \quad _n \quad \nabla h \quad _n}{\mathbf{A} \nabla h \quad _n{}^{2}}$$

$_n$ $_n$ $\boldsymbol{G}$ $_{n-1}$ $_{n-1}$

$_n$ $_n$ $_n$

$_n$ $_{n-1}$ $<$

$p_m^{(k)}$ $_{lmn\,t}$

K

K

K

$_{lmn\,t}$, $p_{\geq K}^{(k)}$

K

$_0$

N^2 N^2

$_{jk\,t}$ $\leq i \leq N$ $\leq j \leq$ $\leq k \leq$ $\leq$ $\leq N$

i $\leq i \leq N$ $\leq$ $\leq N$

$$_{jk\,t} \begin{cases} _t & k \quad \pi_1\ i \qquad j \\ & k \,/\, \pi_1\ i \end{cases}$$

$\leq i \leq N$ $\leq j \leq$ $\leq k \leq$ $\leq$ $\leq N$

N^2 N^2 N^2 $_{jk\,t}$

$_{lmn\,t}$ $i\ k \rightarrow l\ m$ k $\pi_2\ i$

$l\ m$

N^2 N^2 N^2

N N^2

A **b**

$$ {}_{0k\,t} + {}_{1k\,t} + {}_{t} \quad {}_{t} \sum_{\pi_1(\,,s)=k} {}_{0k\,s} \quad {}_{t} \sum_{\pi_1(\,,r)=k} {}_{1k\,r} + $$
$$ {}_{t} \left(\sum_{\pi_1(\,,s)=k} {}_{0k\,s} \right) \left(\sum_{\pi_1(\,,r)=k} {}_{1k\,r} \right) $$

$$ {}_{lmn\,t} \approx {}_{0k\,t} + {}_{1k\,t} + {}_{t} \quad {}_{t} \sum_{\pi_1(\,,s)=k} {}_{0k\,s} \quad {}_{t} \sum_{\pi_1(\,,r)=k} {}_{1k\,r} $$

$i\ k\ l\ m$ $\leq i \leq N$ k $\pi_1\ i$ $i\ k \rightarrow l\ m$ $\pi_1\ l$ $\leq \ \leq N$ K

${}_{jk\,t}$

${}_{jk\,t}$ K ${}_{jk\,t}$

$p_K^{(\ k)}$

K K

Input $i\ k \rightarrow l\ m$ $i\ k;$ ${}_{st}$ s ;

Output

i

${}_{2k\,t}$ ${}_{t}$

k $\pi_1\ i$

${}_{0}$ ${}_{jk\,t}$

$i\ j\ k$;

j K

$$ p_{\geq K}^{(\ k)} \quad \sum_{m=K}^{\infty} p_m^{(\ k)} \quad \frac{{}_{0k} \quad {}_{1k} \ {}^{K-1}}{\left[\quad {}_{0k} \quad {}_{1k} \quad {}_{2k} \right]^{K-2}} $$

${}_{0}$ $p_{\geq K}^{(\ k)}$

$i\ k$

5 A procedure to calculate mean transport delay

$K \quad \infty \qquad {}_{jk} \qquad p_m^{(k)}$

$K \quad \infty \qquad {}_j^{(k)}$

$\delta_k \qquad K \quad \infty$

${}_0^{(k)} > {}_6^{(k)} + {}_7^{(k)} \qquad {}_0^{(k)} > {}_6^{(k)} \quad {}_7^{(k)}$

$$\lim_{K\to\infty} \frac{{}_0^{(k)}\,K \quad {}_6^{(k)} \quad {}_7^{(k)}\,K}{{}_0^{(k)}\,K} \qquad \lim_{K\to\infty} \left(\frac{{}_6^{(k)} \quad {}_7^{(k)}}{{}_0^{(k)}} \right)^K$$

δ_k

$L \qquad K \quad \infty$

$$p_0^{(k)} \quad {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)}$$

$$p_1^{(k)} \quad {}_0^{(k)} \quad {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} / {}_0^{(k)}$$

$$p_m^{(k)} \quad {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} \quad {}_6^{(k)} + {}_7^{(k)}\,{}^{m-1} / {}_0^{(k)}\,{}^{m-1}$$

$m >$

$K \to \infty$

${}_0^{(k)} > {}_6^{(k)} + {}_7^{(k)}$

$$p_\infty^{(k)} \stackrel{\Delta}{} \lim_{m\to\infty} p_m^{(k)} \quad \lim_{m\to\infty} {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} \quad {}_6^{(k)} + {}_7^{(k)}\,{}^{m-1} / {}_0^{(k)}\,{}^{m-1}$$

$j \quad j \geq$

$\mathcal{Q}_k$

$$p_{\geq j}^{(k)} \stackrel{\Delta}{} \sum_{m=j}^{\infty} p_m^{(k)} \qquad \sum_{m=j}^{\infty} {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} \left(\frac{{}_6^{(k)} + {}_7^{(k)}}{{}_0^{(k)}} \right)^{m-1}$$

$$ {}_0^{(k)} \left(\frac{{}_6^{(k)} + {}_7^{(k)}}{{}_0^{(k)}} \right)^{j-1}$$

$$\frac{{}_{0k} \quad {}_{1k}\;{}^{j-1}}{\left[\quad {}_{0k} \qquad {}_{1k} \qquad {}_{2k} \right]^{j-2}}$$

$K \quad \infty \quad i \;\; k \to l \;\; m \qquad \pi_1 \; l \qquad k \quad \pi_1 \; i$

$$ {}_{lmn\,t} \qquad {}_{0k\,t} + \quad {}_{1k\,t} + \quad {}_t \left(\sum_{\pi_1(\;,s)=k} {}_{0k\,s} \right) \left(\sum_{\pi_1(\;,r)=k} {}_{1k\,r} \right)$$

L_k

$${}_2 \quad {}_{02} \quad \delta_{02} + {}_{12} \quad \delta_{12}$$

$${}_{02} + {}_{12} \quad p_K^{(2)} \quad {}_{02} \quad {}_{12}$$

i

$$\sum_{=1}^{N} {}^2$$

,

$\mathcal{Q}_k$ k π_1 i $\mathcal{Q}_k$

$$\frac{{}_{2k\,t} \quad {}_{0k} \quad {}_{1k}\delta_k}{{}_{2k\,t}} \quad {}_{0k} \quad {}_{1k}\delta_k$$

$${}_{0k} \quad {}_{1k}\delta_k$$

$\mathcal{Q}_k$ k π_1 i

i k

x y

x y

${}_{jk\,t}$ $p_K^{(k)}$

${}_{jk\,t}$ $p_K^{(k)}$ N $p_K^{(k)}$

N N ${}_{jk\,t}$

$p_K^{(k)}$ ${}_{jk\,t}$ $p_K^{(k)}$

${}_{jk\,t}$ $p_K^{(k)}$ ${}_{jk\,t}$

$\boldsymbol{G}$

$\triangle \boldsymbol{G}$

$${}_0 \; {}^0 \quad {}_{n+1} \; {}^{n+1} \; \triangle \boldsymbol{G} \; {}_n \; {}^n \quad \cdots \quad {}_0 \; {}^0$$

$${}_0 \; {}^0 \quad {}_1 \; {}^1 \; \cdots$$

$$\delta_{jk t} \quad p_K^{(k)} \quad {}_{jk t} \left(\sum_{\pi_1(,s)=k}^{p_i(s)>p_i(t)} {}_{\bar{j}k s} + \sum_{\pi_1(,r)=k}^{p_i(r)=p_i(t)} {}_{\bar{j}k r} / \right)$$

K $p_K^{(k)}$ $\delta_{jk t}$

$p_K^{(k)}$

;

$\mathcal{Q}_k$

$p_K^{(k)}$

j i ${}_{jk t}$

$\mathcal{Q}_k$

$i\ k \ \rightarrow\ l\ m$ $\mathcal{Q}_k$ $\mathcal{Q}_k$'

' $l\ m$ $\leq m \leq$ $\pi_1\ l$

$${}_{lmn t} \begin{cases} {}_{0k t} \quad \delta_{0k t} + \quad {}_{1k t} \quad \delta_{1k t} + \quad {}_t \quad {}_{0k} \quad {}_{1k} \delta_k & k \quad \pi_1\ i \\ \delta_{k t} & k \quad \pi_2\ i \end{cases}$$

${}_{jk t} \quad \delta_{jk t}$ $\mathcal{Q}_k$ j

$\mathcal{Q}_k$

;

$\mathcal{Q}_k$

${}_{2k t} \qquad {}_t$

$\leq k \leq$ $\pi_1\ i$ k

$${}_{2k} \quad \sum_{\pi_1(,t)=k} \quad {}_t$$

$\leq k \leq$ ${}_{jk} \leq$ $\leq i \leq N$ $\leq j \leq$ $\leq k \leq$

${}_k$ $\mathcal{Q}_k$ $\sum\ \sum_k L_k$

$\sum \quad {}_2$,

$$\frac{\sum_{=1}^{N} \sum_{k=0}^{2} \quad L_k}{\sum_{=1}^{N} \quad {}_2}$$

$\mathcal{Q}_k$ $0k$ $1k$ $2k$ δ_k

jk j δ_k δ $^{(k)}_{j}$

L_k $\mathcal{Q}_k$

$\mathcal{Q}_k$

$$p_0^{(k)} \quad \frac{\delta_k \; {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} \; \delta_k \; {}_0^{(k)\,K}}{\delta_k \; {}_0^{(k)\,K} \quad {}_6^{(k)} + \; {}_7^{(k)\,K}}$$

$$p_1^{(k)} \quad \frac{\delta_k \; {}_0^{(k)} \; \delta_k \; {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} \; \delta_k \; {}_0^{(k)\,K-1}}{\delta_k \; {}_0^{(k)\,K} \quad {}_6^{(k)} + \; {}_7^{(k)\,K}}$$

$$p_m^{(k)} \quad \frac{\delta_k \; {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)} \; \delta_k \; {}_0^{(k)\,K-m} \quad {}_6^{(k)} + \; {}_7^{(k)\,m-1}}{\delta_k \; {}_0^{(k)\,K} \quad {}_6^{(k)} + \; {}_7^{(k)\,K}}$$

$\leq m \leq K$

$$L_k \quad \Big[\quad \delta_k \; {}_0^{(k)} \; \delta_k \; {}_0^{(k)\,K+1} + \; \delta_k \; {}_0^{(k)\,K+1} \quad {}_6^{(k)} + \; {}_7^{(k)}$$
$$\delta_k \; {}_0^{(k)\,K} \quad {}_6^{(k)} + \; {}_7^{(k)\,2} \quad K + \; \delta_k \; {}^{(k)} \quad {}_6^{(k)} + \; {}_7^{(k)\,K} +$$
$$K \quad {}_6^{(k)} + \; {}_7^{(k)\,K+1} \Big] / \Big[\; \delta_k \; {}_0^{(k)\,K} \quad {}_6^{(k)} + \; {}_7^{(k)\,K} \Big] \; \delta_k \; {}_0^{(k)} \quad {}_6^{(k)} \quad {}_7^{(k)}$$

$\delta_{jk\,t}$

$i \; j \; k$ $i \; j \; k'$ k' $\pi_2 \; i$

$\mathcal{A} \quad \stackrel{\Delta}{} \quad \mathcal{Q}_k$

$\mathcal{B} \quad \stackrel{\Delta}{} \quad i \; j \; k$

$\mathcal{C}_s \quad \stackrel{\Delta}{} \quad s \quad p \quad i \; j \; k$

$\mathcal{D}_r \quad \stackrel{\Delta}{} \quad r \quad p \quad i \; j \; k$

$\mathcal{A}$ K $\mathcal{Q}_k$

$\mathcal{Q}_k$ $\mathcal{A}$ $p_K^{(k)}$ $\mathcal{A}$ $\mathcal{B}$

$\mathcal{C}_s$ $\mathcal{D}_r$

$$\mathcal{A} \quad p_K^{(k)}$$
$$\mathcal{B} \quad {}_{jk\,t}$$
$$\mathcal{C}_s \quad {}_{jk\,s} \quad p \;\; s \; > p$$
$$\mathcal{D}_r \quad {}_{jk\,r} \quad p \;\; r \quad p$$

$i \; j \; k$ $\mathcal{A} \quad \mathcal{B} \quad \cup_s \mathcal{C}_s \; + \; \cup_r \mathcal{D}_r \; /$

0 1 2

4 Network analysis

0 1 2 δ

0 1 2 δ

,

fl $_{jk\,t}$

j i k π_1 i $_{jk}$ i j k

$$_{jk} \quad \sum_{t=1}^{N} \quad _{jk\,t}$$

$\delta_{\ jk\ t}$ i j k

$\delta_{\ k\ t}$ $\delta_{\ k}$ $\mathcal{Q}_{\ k}$

$\mathcal{Q}_{\ k}$ $\mathcal{Q}_{\ \bar{k}}$ $\mathcal{Q}_{\ 2}$ k

$$\delta_{\ k\ t} \quad \begin{cases} \delta_{\ 0\bar{k}\ t} + \delta_{\ 1\bar{k}\ t} + \delta_{\ 02\ t} + \delta_{\ 12\ t} & k \quad \pi_2 \ i \\ & \end{cases}$$

$$\delta_{\ k} \quad \sum_{\pi_2(\ ,t)=k} \delta_{\ k\ t}$$

$\leq k \leq$ [‡]

$\mathcal{Q}_{\ k}$

0 1 2 δ $\mathcal{Q}_{\ k}$

---

‡Th d x f mm q. t, d h mm v ll v l f t h f h d π_2 i,t $= k$; m l w ll l d h gh h m d f h .

$\mathbf{P}_{0,0}$ δ 0

$\mathbf{P}_{0,1}$ δ 0 6 7

$\mathbf{P}_{0,2}$ $6+$ 7

$\mathbf{P}_{m,m-1}$ δ 0 $\leq m \leq K$

$\mathbf{P}_{m,m}$ δ 0 6 7 $\leq m < K$

$\mathbf{P}_{m,m+1}$ $6+$ 7 $\leq m < K$

$\mathbf{P}_{K,K}$ δ 0

$p_m^{(n)}$ m

$p_m \overset{\Delta}{} \quad {}_{n\to\infty} p_m^{(n)}$ m

$$\mathbf{p} \overset{\Delta}{} \; p_0 \; p_1 \; \ldots \; p_K$$

$$\mathbf{p} \quad \mathbf{pP}$$

$$p_0 + p_1 + \quad + p_K$$

$\mathbf{p}$

$$p_0 \quad \frac{\delta \; 0 \quad 6 \quad 7 \; \delta \; 0 \; ^K}{\delta \; 0 \; ^K \quad 6 + \; 7 \; ^K}$$

$$p_1 \quad \frac{\delta \; 0 \; \delta \; 0 \quad 6 \quad 7 \; \delta \; 0 \; ^{K-1}}{\delta \; 0 \; ^K \quad 6 + \; 7 \; ^K}$$

$$p_m \quad \frac{\delta \; 0 \quad 6 \quad 7 \; \delta \; 0 \; ^{K-m} \quad 6 + \; 7 \; ^{m-1}}{\delta \; 0 \; ^K \quad 6 + \; 7 \; ^K}$$

$\leq m \leq K$

L

L

$$L \quad \sum_{m=1}^{K} m p_m$$

$$L \quad \Big[\quad \delta \; 0 \; \delta \; 0 \; ^{K+1} + \quad \delta \; 0 \; ^{K+1} \quad 6 + \; 7$$

$$\delta \; 0 \; ^K \quad 6 + \; 7 \; ^2 \quad K + \quad \delta \; 0 \quad 6 + \; 7 \; ^K +$$

$$K \quad 6 + \; 7 \; ^{K+1} \Big] / \{ \; \delta \; 0 \; ^K \quad 6 + \; 7 \; ^K \; \delta \; 0 \quad 6 \quad 7 \; \}$$

$0 \quad \Delta \quad 0 \; 1 \; 2$
$1 \quad \Delta \quad 0 \; 1 \; 2$
$2 \quad \Delta \quad 0 \; 1 \; 2$
$3 \quad \Delta \quad 0 \; 1 \; 2$
$4 \quad \Delta \quad 0 \; 1 \; 2$
$5 \quad \Delta \quad 0 \; 1 \; 2$
$6 \quad \Delta \quad 0 \; 1 \; 2$
$7 \quad \Delta \quad 0 \; 1 \; 2$

j

$0 \quad 3$

$\delta_0 \quad \delta_3$

$0 \; 1 \; 2\delta$

$+$

$\ldots$

$\ldots K$

$1 \quad 2 \quad 4 \quad 7 \; \delta_0 \; \delta_0 \; \delta_3 \quad \delta_3$

$6 \quad 7 \quad 7$

P

K

0 1

2 ;

δ

$\mathcal{Q}_k$

$\mathcal{Q}_k$

$\mathcal{Q}_0$

00 10 20

$\mathcal{Q}_1$

0 1 2

δ

0 1 2δ †

† W d fi $\bar{x} \triangleq -x$ h m l m f x.

,

p_1 p_2 $p_1 > p_2$

i

k k π_1 i

k

—

k—

k

i $\mathcal{Q}_0$ $\mathcal{Q}_1$ $\mathcal{Q}_2$ $\mathcal{Q}_k$ K

$K \geq$ K

K

j k i j k

$_{jk}$ i j k

$\mathcal{Q}_j$

,

3 Queueing-center analysis

$\mathcal{Q}_k$

$\pi_1 \ i$

$\pi_2 \ i$ N

$\{ \pi_1 \ i \quad \pi_2 \ i \quad \leq \quad \leq N \}$ i

$\pi_1 \ i$ i

, ;

p_1

p_2 $p_1 > p_2$

, , ;

p i

$d_1 \ i$ $d_2 \ i$

i $\pi_1 \ i$ $\pi_2 \ i$

$d_2 \ i$ $d_1 \ i$ i

p $d_2 \ i$ $d_1 \ i$ $\leq i \leq N$ $\leq \quad \leq N$

,

p p $d_1 \ i$

p

—

,

,

2 Assumptions and model

N

N

K ;

,

i j $\to$ l m j i m

l

i

j $_j$

π_1 i π_2 i

i

Analyzing Deflection Routing under Nonuniform Traffic*

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Abstract

D fl g d v f d
. F x d g v ’ g g f
d d v d .
f fi f f
f v d “d fl g” f
. T d fl f d f g
.

T d d f g v z g f
f d . I d z
d fl g f . U g d d d
v f d f d fl g d
d g g v d g
d x.

1 Introduction

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*Th w k w ll d h T l mm P j f h CNR f I l , US DARPA MDA C , S f C l f –P fi B ll MICRO g KC F, d h A S d R h g m. A l v f h w d I INFOCOM ’ .