

APPENDIX 1

The derivation of the cumulative probability function from the Reeves probability density function.

The probability density function is:

$$P(r) = \frac{2r}{M(M+1)}$$

The cumulative probability function is given by:

$$C(n) = \sum_{k=1}^n P(k)$$

Substituting for $P(k)$ gives:

$$\begin{aligned} C(n) &= \sum_{k=1}^n \frac{2k}{M(M+1)} \\ C(n) &= \frac{2}{M(M+1)} \sum_{k=1}^n k \end{aligned}$$

Summation of k from 1 to n is given by:

$$\sum_{k=1}^n k = \frac{n(n-1)}{2}$$

$C(n)$ is given by:

$$C(n) = \frac{n(n-1)}{M(M+1)}$$

$$C(n) M(M+1) = n(n-1)$$

Let:

$$x = C(n) M(M+1)$$

Therefore:

$$x = n^2 - n$$

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Re-arranging to form a quadratic:

$$0 = n^2 - n - x$$

Positive roots of a quadratic are given by:

$$r = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

Substituting gives:

$$r = \frac{1 + \sqrt{1 + 4x}}{2}$$

Substituting for x gives:

$$r = \frac{1 + \sqrt{1 + 4C(r)M(M+1)}}{2}$$

APPENDIX 2

Contains the traffic and cost matrix for the multi drop and mesh network design problems.

Multi drop network

Traffic flow.

Node	Town Code	Town	960 Bit Messages/sec	19200 Bit Messages/sec
1	Lon	London		
2	Ash	Ashford	0.0694	0.0694
3	Cha	Chatham	0.0764	0.0222
4	Dov	Dover	0.0417	0.05
5	Has	Hastings	0.1736	0.0694
6	Sou	Southend	0.1042	0.0417
7	Ton	Tonbridge	0.0694	0.0278
8	Cam	Cambridge	0.0417	0.05
9	Can	Canterbury	0.1042	0.0417
10	Che	Chelmsford	0.0833	0.0167
11	Col	Colchester	0.0347	0.0138
12	Fol	Folkstone	0.0347	0.0556
13	Mar	Margate	0.1389	0.0139

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Multi drop network (cont.)

Cost matrix for 1200 bps links.

Node		1	2	3	4	5	6	7	8	9	10	11	12	13
	Town	Lon	Ash	Ch a	Dov	Has	Sou	Ton	Cam	Can	Che	Col	Fol	Mar
1	Lon	-	568	268	344	275	423	370	338	690	634	504	268	736
2	Ash	568	-	439	413	413	286	522	455	431	146	445	639	344
3	Cha	268	439	-	318	154	278	409	172	635	511	484	406	642
4	Dov	344	413	318	-	215	338	220	401	484	471	294	365	561
5	Has	275	413	154	215	-	273	338	287	572	481	408	374	603
6	Sou	423	286	278	338	273	-	457	295	538	357	455	528	502
7	Ton	370	522	409	220	338	457	-	499	517	572	287	312	635
8	Cam	338	455	172	401	287	295	499	-	360	450	270	380	430
9	Can	690	431	635	484	572	538	517	360	-	310	400	410	340
10	Che	634	146	511	471	481	357	572	450	310	-	350	230	290
11	Col	504	445	484	294	408	455	287	270	400	350	-	330	480
12	Fol	268	639	406	365	374	528	312	380	410	230	330	-	400
13	Mar	736	344	642	561	603	502	635	430	340	290	480	400	-

Cost of 9600 bps Links all connect to London.

Node	Town	Cost of 9600 bps link to London
2	Ash	768
3	Cha	468
4	Dov	544
5	Has	475
6	Sou	623
7	Ton	570

Mesh networks k=3, k=4

Traffic flow in Messages per second (all messages 512 bits in length).

Node		1	2	3	4	5	6
	Town	Lon	Ash	Cha	Dov	Has	Sou
1	Lon	-	0.74	2.34	0.1	4.2	5.7
2	Ash		-	2.0	6.4	1.5	6.2
3	Cha			-	8.1	4.3	10
4	Dov				-	8	6.6
5	Has					-	2.8
6	Sou						-

Cost matrix for 2400 bps links.

Node		1	2	3	4	5	6
	Town	Lon	Ash	Cha	Dov	Has	Sou
1	Lon	-	35	31	47	18	24
2	Ash		-	82	75	80	99
3	Cha			-	4	30	15
4	Dov				-	93	14
5	Has					-	11
6	Sou						-

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Cost matrix for 4800 bps links.

Node		1	2	3	4	5	6
	Town	Lon	Ash	Cha	Dov	Has	Sou
1	Lon	-	70	62	94	36	48
2	Ash		-	164	150	160	198
3	Cha			-	8	60	30
4	Dov				-	186	28
5	Has					-	22
6	Sou						-

Cost matrix for 9600 bps links.

Node		1	2	3	4	5	6
	Town	Lon	Ash	Cha	Dov	Has	Sou
1	Lon	-	140	124	188	72	96
2	Ash		-	328	300	320	396
3	Cha			-	16	120	60
4	Dov				-	372	56
5	Has					-	44
6	Sou						-

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Cost matrix for 19200 bps links.

Node		1	2	3	4	5	6
	Town	Lon	Ash	Cha	Dov	Has	Sou
1	Lon	-	280	248	376	144	192
2	Ash		-	656	600	640	792
3	Cha			-	32	240	120
4	Dov				-	744	112
5	Has					-	88
6	Sou						-

APPENDIX 3

Multi drop network problem.

Solution produced using a modified Esau-Williams algorithm. Network has a total cost of 4143 and a mean message end to end delay of 38.9 seconds.

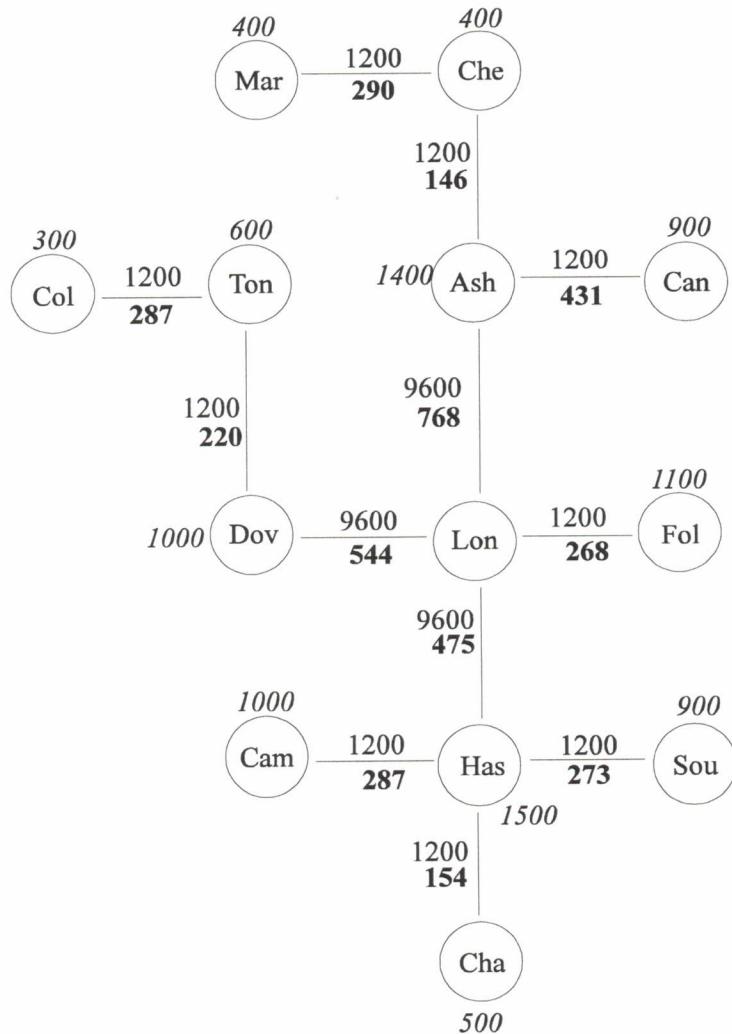


Fig. 10

For each node in the network the volume of traffic in bits per second is shown next to the node in italics. For each link the cost shown in bold and the capacity of the link in bits per second is recorded.

Mesh network k=3.

Solution produced using the link deficit algorithm and minimum hop minimum cost routing. The network has a total cost of 825 and mean message end to end delay of 0.180 seconds.

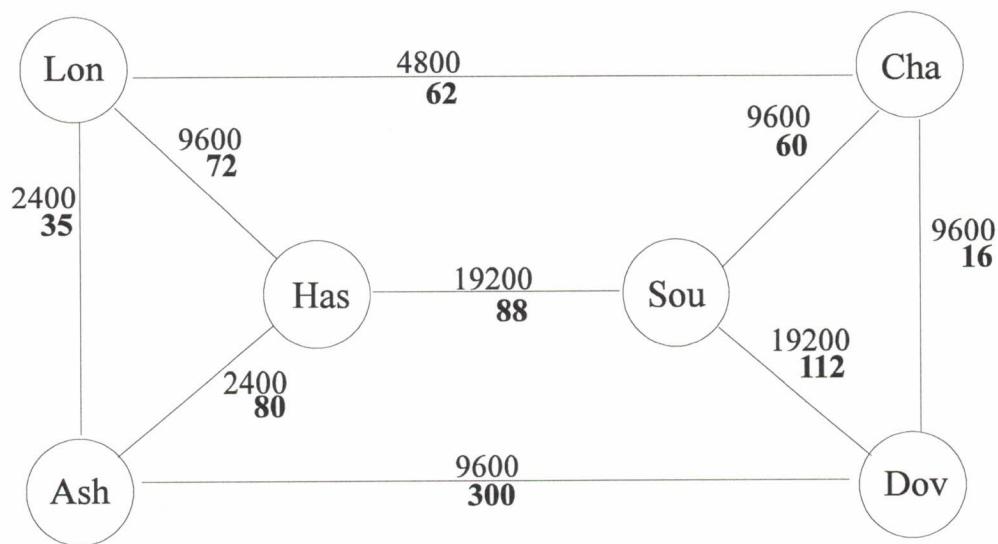


Fig. 11

The network uses the following routing where not direct.

- Lon - Dov via Cha.
- Lon - Sou via Has.
- Ash - Cha via Lon.
- Ash - Sou via Dov.
- Cha - Has via Sou.
- Dov - Has via Sou.

Mesh network k=4.

Solution produced using the link deficit algorithm and minimum hop minimum cost routing. The network has a total cost of 797 and mean message end to end delay of 0.270 seconds.

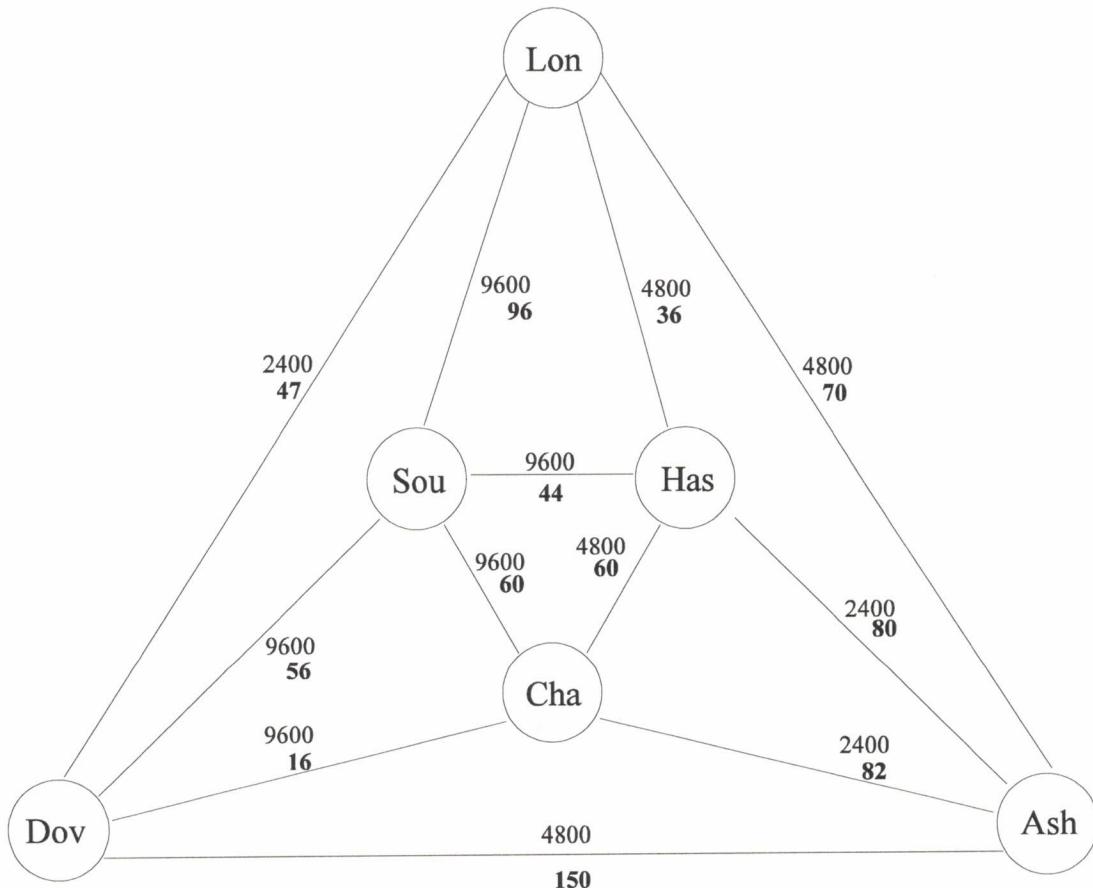


Fig. 12

The network uses the following routing where not direct.

Lon - Cha via Sou.

Ash - Cha via Lon.

Dov - Has via Sou.

APPENDIX 4

Initialisation file for the multi drop network.

[GENETICS]

population_size=400
no_generations=400

[NETWORK]

connectivity_req=1
acceptable_delay=200

[MUTATION]

adddel=10
link=10

[NODES]

node_name=London
node_name=Ashford
node_name=Chatham
node_name=Dover
node_name=Hastings
node_name=Southend
node_name=Tonbridge
node_name=Cambridge
node_name=Canterbury
node_name=Chelmsford
node_name=Colchester
node_name=Folkstone
node_name=Margate

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[LINKS]

```
from=London
to=Ashford
speed=1200
cost=568
from=London
to=Chatham
speed=1200
cost=268
from=London
to=Dover
speed=1200
cost=344
from=London
to=Hastings
speed=1200
cost=275
from=London
to=Southend
speed=1200
cost=423
from=London
to=Tonbridge
speed=1200
cost=370
from=London
to=Cambridge
speed=1200
cost=338
from=London
to=Canterbury
speed=1200
cost=690
from=London
to=Chelmsford
speed=1200
cost=634
from=London
```

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```
to=Colchester
speed=1200
cost=504
from=London
to=Folkstone
speed=1200
cost=268
from=London
to=Margate
speed=1200
cost=736
from=Ashford
to=Chatham
speed=1200
cost=439
from=Ashford
to=Dover
speed=1200
cost=413
from=Ashford
to=Hastings
speed=1200
cost=413
from=Ashford
to=Southend
speed=1200
cost=286
from=Ashford
to=Tonbridge
speed=1200
cost=522
from=Ashford
to=Cambridge
speed=1200
cost=455
from=Ashford
to=Canterbury
speed=1200
```

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```
cost=431
from=Ashford
to=Chelmsford
speed=1200
cost=146
from=Ashford
to=Colchester
speed=1200
cost=445
from=Ashford
to=Folkstone
speed=1200
cost=639
from=Ashford
to=Margate
speed=1200
cost=344
from=Chatham
to=Dover
speed=1200
cost=318
from=Chatham
to=Hastings
speed=1200
cost=154
from=Chatham
to=Southend
speed=1200
cost=278
from=Chatham
to=Tonbridge
speed=1200
cost=409
from=Chatham
to=Cambridge
speed=1200
cost=172
from=Chatham
```

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```
to=Canterbury
speed=1200
cost=635
from=Chatham
to=Chelmsford
speed=1200
cost=511
from=Chatham
to=Colchester
speed=1200
cost=484
from=Chatham
to=Folkstone
speed=1200
cost=406
from=Chatham
to=Margate
speed=1200
cost=642
from=Dover
to=Hastings
speed=1200
cost=215
from=Dover
to=Southend
speed=1200
cost=338
from=Dover
to=Tonbridge
speed=1200
cost=220
from=Dover
to=Cambridge
speed=1200
cost=401
from=Dover
to=Canterbury
speed=1200
```

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cost=484
from=Dover
to=Chelmsford
speed=1200
cost=471
from=Dover
to=Colchester
speed=1200
cost=294
from=Dover
to=Folkstone
speed=1200
cost=365
from=Dover
to=Margate
speed=1200
cost=561
from=Hastings
to=Southend
speed=1200
cost=273
from=Hastings
to=Tonbridge
speed=1200
cost=338
from=Hastings
to=Cambridge
speed=1200
cost=287
from=Hastings
to=Canterbury
speed=1200
cost=572
from=Hastings
to=Chelmsford
speed=1200
cost=481
from=Hastings

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```
to=Colchester
speed=1200
cost=408
from=Hastings
to=Folkstone
speed=1200
cost=374
from=Hastings
to=Margate
speed=1200
cost=603
from=Southend
to=Tonbridge
speed=1200
cost=457
from=Southend
to=Cambridge
speed=1200
cost=295
from=Southend
to=Canterbury
speed=1200
cost=538
from=Southend
to=Chelmsford
speed=1200
cost=357
from=Southend
to=Colchester
speed=1200
cost=455
from=Southend
to=Folkstone
speed=1200
cost=528
from=Southend
to=Margate
speed=1200
```

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```
cost=502
from=Tonbridge
to=Cambridge
speed=1200
cost=499
from=Tonbridge
to=Canterbury
speed=1200
cost=517
from=Tonbridge
to=Chelmsford
speed=1200
cost=572
from=Tonbridge
to=Colchester
speed=1200
cost=287
from=Tonbridge
to=Folkstone
speed=1200
cost=312
from=Tonbridge
to=Margate
speed=1200
cost=635
from=Cambridge
to=Canterbury
speed=1200
cost=360
from=Cambridge
to=Chelmsford
speed=1200
cost=450
from=Cambridge
to=Colchester
speed=1200
cost=270
from=Cambridge
```

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```
to=Folkstone
speed=1200
cost=380
from=Cambridge
to=Margate
speed=1200
cost=430
from=Canterbury
to=Chelmsford
speed=1200
cost=310
from=Canterbury
to=Colchester
speed=1200
cost=400
from=Canterbury
to=Folkstone
speed=1200
cost=410
from=Canterbury
to=Margate
speed=1200
cost=340
from=Chelmsford
to=Colchester
speed=1200
cost=350
from=Chelmsford
to=Folkstone
speed=1200
cost=230
from=Chelmsford
to=Margate
speed=1200
cost=290
from=Colchester
to=Folkstone
speed=1200
```

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```
cost=330
from=Colchester
to=Margate
speed=1200
cost=480
from=Folkstone
to=Margate
speed=1200
cost=400
from=London
to=Ashford
speed=9600
cost=768
from=London
to=Chatham
speed=9600
cost=468
from=London
to=Dover
speed=9600
cost=544
from=London
to=Hastings
speed=9600
cost=475
from=London
to=Southend
speed=9600
cost=623
from=London
to=Tonbridge
speed=9600
cost=570
```

[TRAFFIC]

```
from=Ashford
to=London
no_messages=0.0694
message_len=960
from=Ashford
to=London
no_messages=0.0694
message_len=19200
from=Chatham
to=London
no_messages=0.0764
message_len=960
from=Chatham
to=London
no_messages=0.0222
message_len=19200
from=Dover
to=London
no_messages=0.0417
message_len=960
from=Dover
to=London
no_messages=0.05
message_len=19200
from=Hastings
to=London
no_messages=0.1736
message_len=960
from=Hastings
to=London
no_messages=0.0694
message_len=19200
from=Southend
to=London
no_messages=0.1042
message_len=960
from=Southend
```

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to=London
no_messages=0.0417
message_len=19200
from=Tonbridge
to=London
no_messages=0.0694
message_len=960
from=Tonbridge
to=London
no_messages=0.0277
message_len=19200
from=Cambridge
to=London
no_messages=0.0417
message_len=960
from=Cambridge
to=London
no_messages=0.05
message_len=19200
from=Canterbury
to=London
no_messages=0.1042
message_len=960
from=Canterbury
to=London
no_messages=0.0417
message_len=19200
from=Chelmsford
to=London
no_messages=0.0833
message_len=960
from=Chelmsford
to=London
no_messages=0.0167
message_len=19200
from=Colchester
to=London
no_messages=0.0347

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```
message_len=960
from=Colchester
to=London
no_messages=0.0139
message_len=19200
from=Folkstone
to=London
no_messages=0.0347
message_len=960
from=Folkstone
to=London
no_messages=0.0556
message_len=19200
from=Margate
to=London
no_messages=0.1389
message_len=960
from=Margate
to=London
no_messages=0.0139
message_len=19200
```

Initialisation file for the mesh network k=3 and k=4.

[GENETICS]

population_size=400
no_generations=400

[NETWORK]

connectivity_req=3
acceptable_delay=1

[MUTATION]

adddel=10
link=10

[NODES]

node_name=London
node_name=Ashford
node_name=Chatham
node_name=Dover
node_name=Hastings
node_name=Southend

[LINKS]

```
from=London
to=Ashford
speed=2400
cost=35
from=London
to=Chatham
speed=2400
cost=31
from=London
to=Dover
speed=2400
cost=47
from=London
to=Hastings
speed=2400
cost=18
from=London
to=Southend
speed=2400
cost=24
from=Ashford
to=Chatham
speed=2400
cost=82
from=Ashford
to=Dover
speed=2400
cost=75
from=Ashford
to=Hastings
speed=2400
cost=80
from=Ashford
to=Southend
speed=2400
cost=99
from=Chatham
```

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```
to=Dover
speed=2400
cost=4
from=Chatham
to=Hastings
speed=2400
cost=30
from=Chatham
to=Southend
speed=2400
cost=15
from=Dover
to=Hastings
speed=2400
cost=93
from=Dover
to=Southend
speed=2400
cost=14
from=Hastings
to=Southend
speed=2400
cost=11
from=London
to=Ashford
speed=4800
cost=70
from=London
to=Chatham
speed=4800
cost=62
from=London
to=Dover
speed=4800
cost=94
from=London
to=Hastings
speed=4800
```

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```
cost=36
from=London
to=Southend
speed=4800
cost=48
from=Ashford
to=Chatham
speed=4800
cost=164
from=Ashford
to=Dover
speed=4800
cost=150
from=Ashford
to=Hastings
speed=4800
cost=160
from=Ashford
to=Southend
speed=4800
cost=198
from=Chatham
to=Dover
speed=4800
cost=8
from=Chatham
to=Hastings
speed=4800
cost=60
from=Chatham
to=Southend
speed=4800
cost=30
from=Dover
to=Hastings
speed=4800
cost=186
from=Dover
```

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```
to=Southend
speed=4800
cost=28
from=Hastings
to=Southend
speed=4800
cost=22
from=London
to=Ashford
speed=9600
cost=140
from=London
to=Chatham
speed=9600
cost=124
from=London
to=Dover
speed=9600
cost=188
from=London
to=Hastings
speed=9600
cost=72
from=London
to=Southend
speed=9600
cost=96
from=Ashford
to=Chatham
speed=9600
cost=328
from=Ashford
to=Dover
speed=9600
cost=300
from=Ashford
to=Hastings
speed=9600
```

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```
cost=320
from=Ashford
to=Southend
speed=9600
cost=396
from=Chatham
to=Dover
speed=9600
cost=16
from=Chatham
to=Hastings
speed=9600
cost=120
from=Chatham
to=Southend
speed=9600
cost=60
from=Dover
to=Hastings
speed=9600
cost=372
from=Dover
to=Southend
speed=9600
cost=56
from=Hastings
to=Southend
speed=9600
cost=44
from=London
to=Ashford
speed=19200
cost=280
from=London
to=Chatham
speed=19200
cost=248
from=London
```

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```
to=Dover
speed=19200
cost=376
from=London
to=Hastings
speed=19200
cost=144
from=London
to=Southend
speed=19200
cost=192
from=Ashford
to=Chatham
speed=19200
cost=656
from=Ashford
to=Dover
speed=19200
cost=600
from=Ashford
to=Hastings
speed=19200
cost=640
from=Ashford
to=Southend
speed=19200
cost=792
from=Chatham
to=Dover
speed=19200
cost=32
from=Chatham
to=Hastings
speed=19200
cost=240
from=Chatham
to=Southend
speed=19200
```

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```
cost=120
from=Dover
to=Hastings
speed=19200
cost=744
from=Dover
to=Southend
speed=19200
cost=112
from=Hastings
to=Southend
speed=19200
cost=88
```

[TRAFFIC]

```
from=London
to=Ashford
no_messages=0.74
message_len=512
from=London
to=Chatham
no_messages=2.34
message_len=512
from=London
to=Dover
no_messages=0.1
message_len=512
from=London
to=Hastings
no_messages=4.2
message_len=512
from=London
to=Southend
no_messages=5.7
message_len=512
from=Ashford
to=Chatham
no_messages=2.0
message_len=512
from=Ashford
to=Dover
no_messages=6.4
message_len=512
from=Ashford
to=Hastings
no_messages=1.5
message_len=512
from=Ashford
to=Southend
no_messages=6.2
message_len=512
from=Chatham
```

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```
to=Dover
no_messages=8.1
message_len=512
from=Chatham
to=Hastings
no_messages=4.3
message_len=512
from=Chatham
to=Southend
no_messages=10
message_len=512
from=Dover
to=Hastings
no_messages=8
message_len=512
from=Dover
to=Southend
no_messages=6.6
message_len=512
from=Hastings
to=Southend
no_messages=2.8
message_len=512
```

